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ESTABLISHMENT OF OPERATIONAL GUIDELINES FOR TEXAS COASTAL ZONE MANAGEMENT

Final Report on Example Application I: Implications of Alternative Public Policy Decisions Concerning Growth and Environment on Coastal Electric Utilities

CENTER FOR RESEARCH IN WATER RESOURCES
Department of Civil Engineering
The University of Texas at Austin
Austin, Texas

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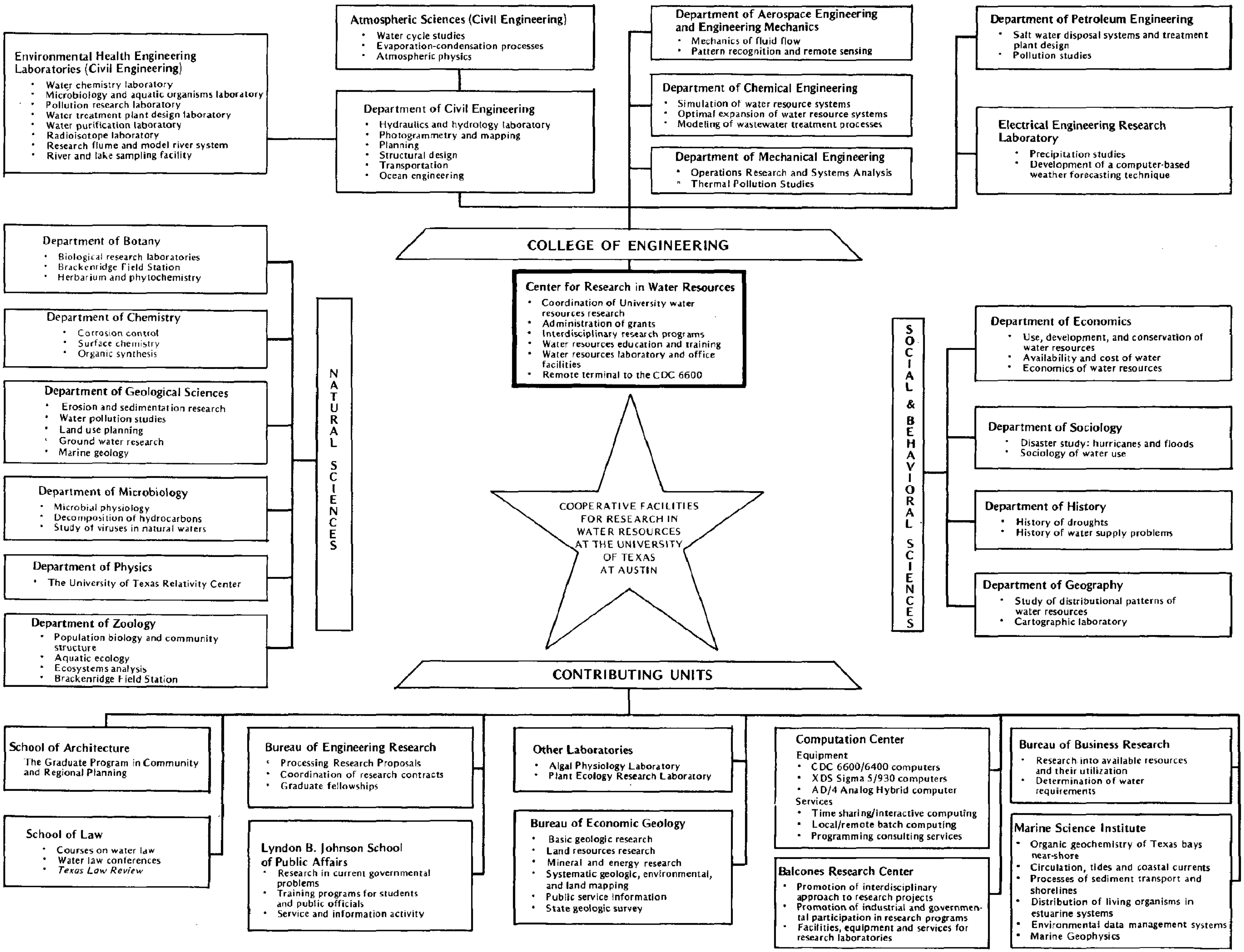

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ESTABLISHMENT OF OPERATIONAL GUIDELINES FOR TEXAS COASTAL ZONE MANAGEMENT

Final Report on
EXAMPLE APPLICATION I.

IMPLICATIONS OF ALTERNATIVE PUBLIC POLICY DECISIONS CONCERNING GROWTH AND ENVIRONMENT ON COASTAL ELECTRIC UTILITIES

Prepared by
Joe C. Moseley II

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Research Applied to National Needs Program
National Science Foundation
Grant No. GI-34870X

U.S. DEPARTMENT OF COMMERCE NOAA
COASTAL SERVICES CENTER
2234 SOUTH HOBSON AVENUE
CHARLESTON, SC 29405-2413

and

Division of Planning Coordination
Office of the Governor of Texas
Interagency Cooperation Contract No. IAC (74-75)-0685

Coordinated through
Division of Natural Resources and Environment
The University of Texas at Austin

This is one in a series of eight final reports describing progress on this research project for the period June 1, 1972, to May 31, 1974. The eight reports are:

- Summary
- Economics & Land Use
- Water Needs & Residuals Management
- Estuarine Modeling
- Resource Capability Units
- Biological Uses Criteria
- Example Application I. Implications of Alternative Public Policy Decisions Concerning Growth & Environment on Coastal Electric Utilities
- Example Application II. Evaluation of Hypothetical Management Policies for the Coastal Bend Region

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ACKNOWLEDGMENTS

This project was possible only with the support and assistance of many organizations and individuals. The over-all effort, of which this is an adjunct, is supported by a grant from the National Science Foundation, Research Applied to National Needs Program (GI-34870X), and by a contract from the Office of the Governor of Texas (IAC (74-75)-0685.)

Some of those providing particularly valuable assistance are listed below and gratefully acknowledged:

Office of Information Services (Office of the Governor) - Dr. Herb Grubb and Dr. Bill Lesso

Governor's Advisory Committee on Power Plant Siting, especially Howard Drew, Chairman; Fred Repper, Vice-President of Central Power and Light Company; D.E. Simmons, Vice-President of Houston Lighting and Power Company; and Charlie Cooke, Staff Director

Texas Water Development Board

Texas Water Quality Board

Texas Coastal and Marine Council

Environmental Protection Agency

Corps of Engineers

Also, Dr. Richard Kolf's efforts as NSF-RANN Project Officer are appreciated.

The author and principal researcher of this report thanks the State of Texas for its implicit support. During all of this work he was employed by the State, first in the Governor's Office and later as the Executive Director of the Texas Coastal and Marine Council. It was principally through the continual responsibility in these two positions that he was able to focus this effort on producing a technique that can be immediately applied in the real world.

ABSTRACT

The principal objective of this project was to develop a methodology for assessing the implications of alternative public policies concerning growth and environmental control in electric power production, including a feasibility demonstration on a real-world problem. Public policies, rather than specific regulatory aspects were stressed because there is a crying need to carefully examine alternative policies for possible adverse impacts. This would be greatly preferable to heated confrontations over specific regulatory decisions, although the author realizes that the latter approach presently prevails.

This effort simultaneously examined three alternative growth policies and three alternative cooling policies in the Corpus Christi area; this results in nine alternative futures. The growth policies ranged from zero population growth to an extrapolation of past trends. Various cooling techniques were applied to meet environmental criteria, which ranged from "continuation of present practice" to "zero-discharge", while satisfying electrical demand for the three growth levels. The implications of these "alternative futures" upon natural resource requirements, costs, and possible socio-economic impacts were carefully displayed and assessed.

All work was done emphasizing existing techniques and real-world data. For example, the Region Seven Texas Input-Output Model proved invaluable, as did the cooperation and assistance of many influential public and private officials.

Several interesting, and timely, findings were produced. (1) It is possible to develop, mostly from existing techniques and data, a methodology for examining the implications of alternative public policy decisions. (2) Application to a real-world problem, in cooperation with leaders from the public

and private sectors, revealed that (a) such an analytical method can be applied to real-world problems and the results achieve respect and consideration by decision-makers; (b) natural resource availability may override dollar costs in selecting a cooling system; and (c) the socio-economic implications of very stringent environmental protection policies can be substantial--in this case the zero-discharge policy, applied to power plants only, would annually cost the typical family one month's rent. (3) Quantitative evidence is produced to substantiate the need for carefully assessing the long-term, often pervasive, implications of public policy decisions.

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CHAPTER I

INTRODUCTION

I.1 BACKGROUND AND NEED

Recent years have witnessed the growth of great public concern over first the environment and then energy. The environmental movement began in the mid-1960's and was initially focused on air and water pollution, but evolved into an overall concern about the "quality of life", national growth trends, consumption or irreversible destruction of natural resources, etc. Public concerns spurred governmental entities at all levels, from city council to the Congress, to take sweeping actions, both in the reorganization of existing agencies and the anactment of tough, new laws. The private sector also responded, although somewhat more slowly.

Public awareness over energy supplies is a more recent phenomenon. Although warnings were broadcast by industry and certain government circles, these prognostications of gloom were largely ignored. Many regarded such dire statements only as part of a propaganda effort to relax environmental criteria and increase prices.

The principal variables being considered in this project deal directly with energy and environmental considerations; however, the economic implications are continually evaluated and displayed. Without a healthy economic system, we would not be able to have either ample, affordable energy or a pleasant environment. A real and significant cost is associated with attaining either. The cost of providing each increases if both are to be realized.

A confrontation between energy production and environmental preservation is inevitable, since many environmental constraints do make the development and utilization of energy resources, including the transformation between energy forms, both more difficult and more expensive. For example: (a) the water quality laws have made it much more difficult to locate electric power generating plants and handle heated effluents in an acceptable manner; (b) fear for the marine ecosystem has caused strong opposition to the development of offshore oil and gas reserves; (c) air regulations have precluded the use of high-sulphur fuels; and (d) public concern over environmentally destructive land-use practices has limited strip-mining.

Such a conflict is most unfortunate, since both a clean environment and a plentiful supply of inexpensive energy are necessary for the "quality of life" that most Americans have become accustomed to enjoying and the others strive to achieve. At the heart of this confrontation is a more basic issue, "growth". The question here is very simple: "How much can we increase in size and/or consumption and still enjoy the amenities of life when these amenities are based on a finite, dwindling supply of natural resources?"

Emotions run high on both sides of the energy-environment dilemma, with heated rhetoric and "black hat-white hat" accusations characterizing entrenched, adversary positions. All sides frequently use selected data to substantiate their positions. The problems are most complex, going straight to the heart of our socio-economic system, political structure, and body of natural resource science. Creative cooperation must replace adversary positions and name-calling if the energy-environment dilemma is to be resolved.

The project that this report describes has, as its principal goal, the development of a methodology that will utilize available information and analytical capability on one segment of the energy-environment dilemma in an attempt to replace accusations with valid scientific facts. In order to accomplish this goal within the available time and manpower constraints, it is necessary to focus on one part of the overall problem. Thus, this effort concentrates on the implications of public policy decisions regarding growth and environmental control as they impact on the electric power industry in South Texas.

The decision to focus on the broad implications of public policy decisions rather than to emphasize specific criteria and regulatory standards is one of the most unusual--and important--features of this entire project. Frequently much effort goes into the detailed investigations of the impact of a single facility and the establishment of particular criteria applicable to that individual facility. This is readily apparent from the reams of reports that are generated on the environmental impact of large projects such as nuclear power plants, offshore oil and gas developments, major reservoirs, etc. A large quantity of data is compiled and scrutinized by some of the best available scientists to assess the possible adverse effects and determine ways of minimizing undesirable environmental impacts. Millions of dollars are routinely spent on such studies just to determine precisely where an outfall should be located, or how close to particularly valuable environmental areas oil drilling should be allowed. Such specific technical decisions are made for the purpose of complying with some previously established public policy, i.e., the National Environmental Policy Act (PL 91-190) or the Water Pollution Control Act Amendments (PL 92-500), or to satisfy public opinion.

It is startling, and possibly even unnerving, to comprehend how much concentrated efforts and valid scientific facts are amassed in order to comply with public policies, and yet suddenly realize that very little technical expertise and thought go into the development of such public policies. Or, stated another way, emotions usually control the establishment of public policies, and after such policies are established, science and technology are brought in to determine how to best achieve these policies. Regrettably, at the time such policies are established, there has usually been no serious effort to assess the overall long-range economic and environmental implications of such policy decisions. What makes this approach doubly unfortunate is the fact that the data and analytical techniques (although they may be fragmented and scattered) usually exist to assess the subtle and often counter-productive implications of such policy decisions.* This does not suggest that technocrats should be allowed to set public policy, but rather that those responsible for establishing public policies should have the technocrats evaluate the implications of proposed public policies before such policies are adopted.**

Obviously there is a pressing need to have available a methodology for assessing the broad, long-term implications of public policy decisions relating to the energy-environment dilemma. It is critical that these assessments be made at the policy formulation stage, before such policies are adopted. If a true balancing of needs is to be achieved, it is necessary to bring scientific and technical expertise to bear at the strategic level of policy decision-making, rather than at the tactical level of program implementation. Thus, this project attempts to respond to a real, pressing need by developing and testing a procedure for evaluating the implications of alternative public policy decisions.

I.2 OBJECTIVES AND SCOPE

The overall goal is to develop a methodology for assessing the long-term, and often subtle, implications of public policy decisions impacting on the energy-environment dilemma. The results obtained should have two principal effects:

* Many examples could be cited, such as the impact on gasoline consumption of automobile emission controls, added fuel consumption of dry cooling towers, etc., but these alone constitute plenty of materials for another sizable investigation.

** The Congress has taken a significant step in this direction by the passage of PL 92-484 which established the Technical Assessment Act of 1972 that has the mission of assessing the scientific requirements and/or implications of laws before they are enacted.

1. Defuse much of the current emotional nature which results in adversary positions, and mellow such confrontations with a strong body of viable, acceptable scientific fact. Such action could greatly improve the climate for the constructive cooperation that will ultimately be required to attain the necessary compromises.
2. Inform those elected and/or appointed officials who are responsible for establishing public policies of the probable consequences of their actions. This should help in the adoption of policies which accomplish their stated objectives within a framework of what is realistically possible.

Specifically, this investigation has the following objectives:

1. to develop a methodology for assessing the implications of alternative public policies concerning growth and environmental control of electric power production;
2. to apply this methodology to a real-world situation in order to insure that all necessary factors have been incorporated and to demonstrate its practical applicability and utility to those decision-makers who could possibly benefit from its application to certain of their problems; and
3. to gain experience from this application and use such expertise in the second year of a broader project of which this is one element.*

* This project has a dual role: (a) it is a stand-alone investigation of energy-environment considerations, and (b) it is a leading effort in a broader NSF-RANN and Governor's Office sponsored project aimed at evaluating a spectrum of alternative public policies and developing operational guidelines for coastal zone management. (Fruh, et al, 1972; Fruh, et al, 1973)

The above objectives are rather broad, and it was necessary to limit the scope and intensity of this investigation to something that could be realistically accomplished within the time and resources available. The entire project was subjected to the following scope and limitations:

1. Two public policies, growth and environmental control, are examined, and three alternative "levels" of each are considered. This results in nine "alternative futures" for each point in time.
2. The growth policy consists of three projected levels, one each corresponding to a very low growth rate, a very large growth rate, and an intermediate value. For easy identification these are named ZPG (Zero Population Growth), COC (Chamber of Commerce), and INT (Intermediate).
3. Environmental control was limited to waste heat dissipation. Three alternative policies are formulated, with each being based upon some realistically conceivable regulatory approach. They are a continuation of present practices, a zero-heat discharge to the aquatic environment (the stated 1985 goal of the 1972 amendments to the Water Pollution Control Act) and an intermediate policy which would hold total heat release at current levels. Figure I.2A shows how the alternative policies combine to produce nine alternative futures.
4. The study area is the 13-county portion of South Texas surrounding Corpus Christi that corresponds to the Coastal Bend State Planning Region. This part of the Texas Coastal Zone was chosen for the following reasons: (a) the area is a logical compromise between the urbanized and the undeveloped regions of the Texas Coastal Zone and as such it provided all the realistic features needed for analysis yet was not hopelessly large; (b) institutions, both public and private, in the region expressed a willingness to cooperate; (c) the region presents a spectrum of characteristics, urban-rural settings, heavy industry, tourism, agriculture, etc., that would

COOLING POLICY

GROWTH POLICY	C_1	C_2	C_3
ZPG			
INT		R_{ij}	
COC			

ABBREVIATIONS

C1 = COOLING POLICY - PRESENT PRACTICE
C2 = " " - CONSTANT BTU DISCHARGE
C3 = " " - ZERO BTU DISCHARGE
ZPG = GROWTH POLICY - ZERO POPULATION GROWTH
INT = " " - INTERMEDIATE
COC = " " - CHAMBER OF COMMERCE
R_{ij} = RESPONSE CORRESPONDING TO POLICIES Wji, THIS CAN BE ANY OF A NUMBER OF MEASURES SUCH AS WATER REQUIREMENTS, COSTS, DECREASE IN DISCRETIONARY INCOME, ETC.

NINE ALTERNATIVE FUTURES CONSIDERED

FIGURE 1. 2A

tend to make the procedure more widely applicable; (d) the region closely corresponds to the principal service area of a single, major electric utility; and (e) the institution doing the research maintains a field campus in the area.

5. The time period under consideration covered 1970 to 1990.
6. Power production and cooling technology are limited to existing methods and those currently under development that are anticipated to be operational by the early 1990's.
7. Existing information and analytical techniques are used. Heavy reliance is placed on the Texas Input-Output Project's Region 9 Model, and other necessary data are accumulated from a variety of available reports, and in a few instances from proprietary private sources.
8. Every effort is made to: (a) use real-world data and make no assumptions that would destroy the reality of the results; (b) display the results in a simple, easily understood manner; and (c) while focusing in on one particular area, keep the methodology general enough so that with new data and only minor analytical adjustments the technique can be transferred to another area and applied to similar problems.
9. Principal measures of system response to the alternative policies include quantitative evaluations of (a) resource consumption, i.e., water use, land requirement; (b) direct dollar costs of satisfying each alternative; and (c) the indirect and induced economic impacts of such expenditures. In addition, quantitative comparisons were made considering household and commercial expenditures and other economic characteristics in an attempt to identify and assess some of the socio-economic implications of the alternative futures.
10. All study parameters can be placed into one of three categories: state, independent, or dependent variable. They are shown so classified in Table I.2A.

STATE VARIABLES

1. STUDY AREA
2. TIME FRAME
3. EXISTING TECHNOLOGY, COSTS & PERFORMANCE

INDEPENDENT VARIABLES

1. GROWTH POLICIES
   - A. ZPG
   - B. INT
   - C. COC
2. ENVIRONMENTAL (COOLING) POLICIES
   - A. PRESENT PRACTICE
   - B. CONSTANT BTU DISCHARGE
   - C. ZERO BTU DISCHARGE

DEPENDENT VARIABLES

1. RESOURCE REQUIREMENTS
2. DIRECT COST (s) OF COOLING
3. INDIRECT AND INDUCED COSTS OF COOLING
   - A. $/FAMILY/YEAR
   - B. PERCENT ANNUAL RENT PAYMENTS
   - C. IMPACT ON DISCRETIONARY INCOME FOR BOTH HOUSEHOLDS AND SELECT INDUSTRIES

CLASSIFICATION OF PRINCIPAL STUDY PARAMETERS

TABLE 1.2A

I.3 METHODOLOGY

The general analytical procedure contained five principal steps:

1. Postulate Alternative Public Policies - Determine policies to be studied and develop quantitative projections of each.
2. Devise Technical Base Needed - Determine what kind of technological devices will be needed to satisfy the alternative policies. Establish their principal characteristics, including operating requirements and costs.
3. A: Quantify Alternative Futures - Develop specific, quantitative descriptions of the various futures from the policy alternatives.

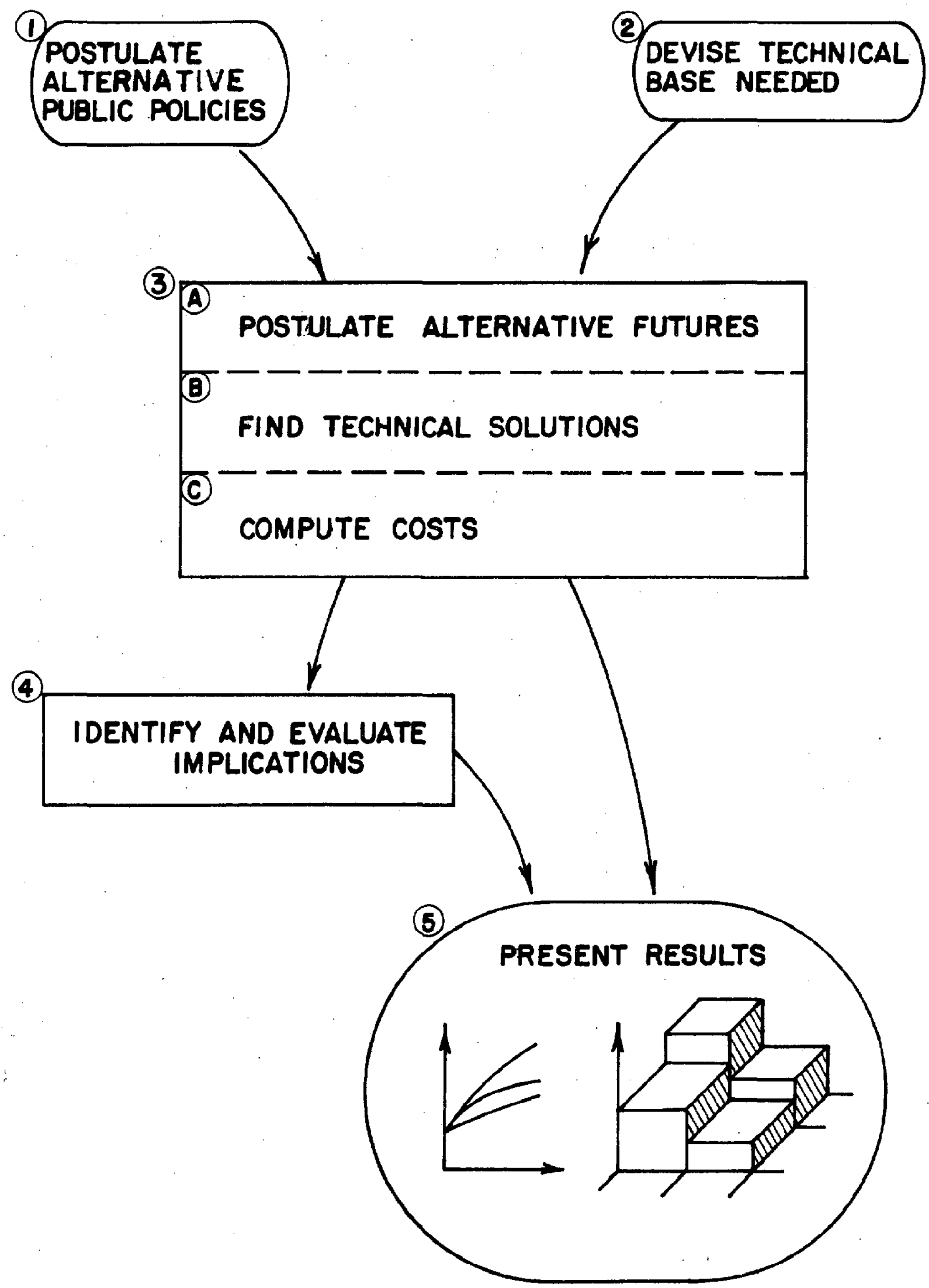
   B: Find Technical Solutions - Determine ways to use the technology developed in step 2 in order to achieve the alternative requirements in compliance with policies.

   C: Compute Costs - Determine what it will cost, in resources as well as dollars, to satisfy the alternative futures.
4. Identify and Evaluate Implications - Determine what the indirect and induced effects of satisfying each alternative future will be, and assess, in broad terms, just what the socio-economic and institutional implications of such actions are apt to be. (While the other steps are purely quantitative, this one is partially qualitative and relies heavily on intuition.)
5. Present Results - Be as non-technical as possible in the presentation of the results so that non-analysts will be able to follow them.

The analysis and discussions presented in later chapters all fit into the above general framework (see Figure I.3A).

I.4 SUMMARY OF FINDINGS

The detailed results are given in Chapter V and the conclusions and



OVER-ALL ANALYTICAL METHODOLOGY
FIGURE I. 3A

recommendations are presented in Chapter VI. From these two general findings stand out:

1. Application of the methodology to a real-world problem demonstrated that the technique can, if applied carefully, reveal major, long-range implications and subtle side-effects of alternative public policies.
2. Development of this procedure with its heavy reliance on available techniques and data, strongly suggests that similar investigations of the consequences of alternative public policy decisions could be conducted on a number of topics without a significant increase in basic research and data collection. Rather, what is needed is (a) a thorough understanding of the policy aspects of the problem at hand; (b) the capability to present the significant questions in a quantitative manner; (c) a sound, working knowledge of available analytical techniques; and (d) presentation of results in a form that is meaningful to policy makers as well as analysts.

The South Texas case study revealed several interesting facts. While some results are general, others are applicable only to that region; however, all provide interesting insight into the complex nature of the problem under consideration:

1. The "cost" in the consumption of certain natural resources, such as water, fuel, or land, may preclude the use of certain cooling techniques. At times, such "resource costs" may override conventional dollar costs in the selection of a cooling system.
2. Under certain conditions a solution to one environmental ill may create another environmental problem which is worse than the original difficulty.
3. Considering only cooling water for power plants, attainment of the "zero waste discharge" goal by 1985, as prescribed by law, will have a significant socio-economic impact on this region

where the average annual per capita income is only $652. For example, meeting these standards would place a total cost burden on the typical family equivalent to one month's average rent, namely $74.*

4. Although there will be marked economic impacts on some sectors in this area and the cost increases may drive some marginal establishments out of business, no broad "inflationary waves" will be triggered.

The results lend strong quantitative evidence to the argument that detailed analysis should be done of the possible implications of public policy decisions before such decisions are made.

While sufficient data and analytical capability are available to assess environmental and economic impacts and every effort should be made to apply such resources now, the need for quantitative information on sociological and socio-economic aspects is particularly acute.

I.5 CONTENTS

This report is divided into six chapters in the following manner:

Chapter I: Introduction covers the background, need, scope, objectives, and provides a concise statement of the principal findings.

Chapter II: The Problem discusses the need to resolve the energy-environment dilemma, and explores the basic conflicts between growth and environmental protection. It culminates with the development and presentation

* This total cost burden includes direct, indirect, and induced costs. Direct cost is the increase in the monthly household electric bill; indirect and induced costs reflect the increased cost that will be contained in the goods and services purchased by the household. See Chapter V for details.

of an analytical approach for evaluating and comparing the implications of alternative public policies.

Chapter III: Alternative Public Policies explains why the policies "growth" and "power plant cooling" were chosen for the test case, and presents the details of how the alternatives of each were developed and quantified.

Chapter IV: Technical Considerations in the Production and Movement of Electric Power contains the information base needed to develop the characteristics and assumptions concerning technical aspects of heat rejection requirements, alternative cooling processes, resource requirements, dollar costs, reliability, etc. These are necessary in developing estimates of resource requirements and economic impact needed to assess the overall impact and implications of the policy alternatives.

Chapter V: Results and Analysis combines the quantified policies, with the appropriate technical background information, and takes them the final step, by performing the analyses which are the central objective of this investigation.

Chapter VI: Conclusions and Recommendations presents the principal findings of this project.

CHAPTER II
THE PROBLEM

The resolution of the energy-environment dilemma is one of the major difficulties facing our society today. Almost all aspects of our daily lives are dependent upon abundant, relatively inexpensive energy in many forms. The great bulk of this energy comes--either directly or indirectly--from limited fossil fuels which are rapidly being depleted. Simultaneously, strong drives are being mounted to clean up the environment, to eliminate pollution, and to provide an "improved quality of life".

The electric power industry--which is a multi-billion-dollar series of complex private-public entities, all operating as a regulated monopoly--is often caught in the middle of this controversy. Undoubtedly, electricity is the cleanest energy to move and use; however, many problems can arise during generation or development of this secondary form of energy. Emotions run high on both sides of the electric power-environment conflicts, characterized by strong stances and a reluctance to compromise. Misinformation abounds; in many instances there is no adequate information base or viable method by which to compare and ultimately resolve the two positions in a realistic and reasonable fashion.

Before the conflicting positions can be resolved, it is necessary to develop a method for comparing the characteristics and implications of the alternatives. The objective of this chapter is to supply vital background information on both the energy and water situations; illustrate the basic conflicts involved; demonstrate the need for a comparative analytical approach which satisfies stringent conditions of transformability, analytical acceptability, and interpretability; and lastly, to present a method that is capable of comparing, in a realistic manner, the selected alternatives.

II.1 GROWTH AND ENVIRONMENTAL CONFLICTS

Our present society is the product of a long growth-oriented heritage: almost all activities in the past have stressed growth and development aimed at improving the quantity and quality of goods and services available to Americans. In pursuing this goal, the United States has consumed copious quantities of energy of all forms, as well as most other available natural resources. Currently the United States consumes 27 percent of the world's total energy yet has only 3 percent of the world's population. (Shell, 1972)

Electrical power is a derived or secondary form of energy which requires some primary form to operate the generation process. Of the present U.S. daily energy consumption of approximately 35 million barrel-equivalents, or 2.03×10^{14} BTU*, about one-quarter or 8.75 million barrel-equivalents (5.07×10^{13} BTU's) are used to produce electrical power. (Shell, 1972) In the past the principal forms of primary energy used to produce electricity have been coal, natural gas and oil, supplemented with some hydro-electric generation; nuclear energy has become a recent addition, but still accounts for less than 1 percent.

While electricity is unquestionably the "cleanest" and most environmentally-acceptable form of energy to transport and use, many persons have severely attacked it on environmental grounds because of the hazards involved in the production of the primary energy source (e.g., oil spills, strip mining) or during the conversion from the primary form to electricity (e.g., air emissions from coal/oil fired plants, or thermal discharges from steam plants). Substantial

* For purposes of this report, the common conversion factor of 5.8×10^6 BTU per Bbl of crude oil is used.

disagreements have also arisen over the safety features and siting of nuclear plants.

Environmental arguments against power plants often go further than just disagreements over whether or not a given plant, or its fuel supply will adversely affect the environment in direct ways: expansion of electrical generating capacity offers a good focal point for people who oppose in general all forms of additional growth. Power plants make an ideal soapbox for such confrontations. They are highly visible; almost everyone knows what a power plant looks like and can think of several good reasons why it should not be located in any given spot. Since power is continually available to all persons in essentially unlimited quantities, it is impossible for most people to visualize how "not having just that one more plant" will adversely affect them.

Some power plants have had unfavorable localized impacts, the more vivid examples being dark air emissions, strip mining abuses, oil spills, etc. Also negatively influencing public opinion are the electrical bills which come to every household in the United States, 12 times per year, as a persistent reminder that electricity is still alive and well.

Because of these highly visible characteristics the power industry, along with highways, water resources, and others, has become a common point of attack for those espousing a no-growth or a greatly reduced growth philosophy. Many of these conflicts are taken into the courtroom; currently there are more than 125 power plant related cases before the courts. (Personal Communication-Governor's Office)

Controversies over power plant siting, pollution control and fuel supply have produced some of the most violent conflicts of the environmental movement. Typical examples include the effective blocking of all new power plants in Consolidated Edison's system, and the now-famous Calvert Cliffs Decision in Maryland. Texas has not been without problems either, as witnessed by the long and indeterminate fight over Houston Lighting and Power's Cedar Bayou facility.

Unfortunately, almost everyone suffers in these kinds of confrontations: the environmentalists trying to stop a project often succeed only in delaying construction for a while; the utility companies' costs go up because of inflation and costly court battles; and the public has to wait longer to get additional power supplies, with the costs being inevitably higher. This does not imply, however, that resorting to litigation is always bad. Court actions have produced some valuable benefits to the public. For example, some truly "bad" or unnecessary projects have been eliminated. In many other cases both the project developer and the involved regulatory agencies have been forced to take a more careful look at what they were doing and as a result, have often come up with alternatives or improved modifications which have made the entire venture much more acceptable to all those concerned.

Current attitudes and trends indicate that these disagreements and confrontations, while they may change in specific characteristics, are nonetheless apt to continue because of the diversity of interests and beliefs. The rapidly developing energy crisis is likely to have a stimulating impact on both groups. Those responsible for providing power will say - "Let's hurry up and build more facilities." Those opposing additional growth will predictably caution - "Look, we've already exceeded what we can safely and consistently provide over long periods, so let's simply learn to live with less energy."

The ultimate resolution to this dilemma can only come from a general migration of public attitude toward one camp or the other. In the meantime, it would be most desirable and valuable for all persons involved, whether or not they favor proposed growth or environmental policies or a mixture of both, to have some techniques to evaluate the broad impact of various decisions on the future. Such information could intelligently alter major resource allocation decisions being made today by both private enterprise and government.

II.2 THE NATIONAL ENERGY SITUATION

The United States is rapidly moving toward a major energy crisis.* Some hopeful persons prefer to call it a "gap" rather than a "crisis", but this is merely a game of words. A society as heavily dependent on energy for all aspects of its routine functioning as ours is, cannot span a significant "gap" between the requirement for energy and its supply, without certain routine functions being substantially curtailed or even eliminated. By definition then, we are in the midst of an energy crisis.

The situation has not developed overnight, though the general public awareness of the pending severe energy shortage has been triggered by a series of "enlightening" events. For the first time in the nation's peacetime history, motorists are being faced with shortages and almost certain rationing of gasoline supplies. Also, during the summer of 1973, certain areas including Austin and San Antonio, were faced with the possibility of having to ration electric power to customers because of a shortage of the basic fuel used for generating purposes. Yet, less than a year ago, during the fall of 1972, voters in Austin initially defeated a bond issue to finance the city's participation in the joint construction with several other utility companies of a nuclear power plant. That same year, The University of Texas remained shut down during a severe winter cold spell because it could not get natural gas to operate its power generation and heating plants. These are only a few close-to-home examples illustrating the real nature of the problem confronting us.

* Webster defines crisis as "An unstable or crucial time or state of affairs; specifically: the period of strain following the culmination of a period of business prosperity when forced liquidation occurs."

Present and Projected Energy Usage

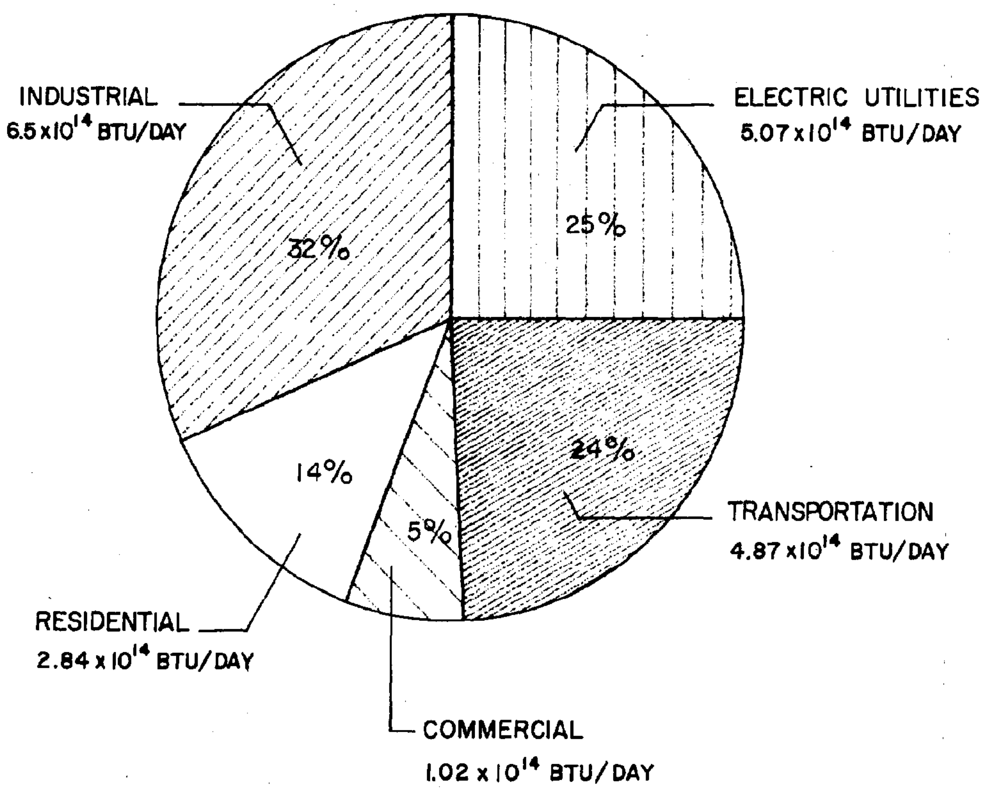
The complexity of the "energy problem" is overwhelming when viewed in its totality. A brief presentation of the current and projected U.S. energy usage will give us a perspective on the problem.

Present energy usage in the U.S. is fact and can be thoroughly documented. Attempting to project future consumption, and to identify the alternative sources is substantially more difficult. Many "authorities" exist on the subject, each with its own unique characteristics and positions, but agreeing on most significant features. In this study a variety of the different broad analyses and projections were reviewed (National Petroleum Council, 1972; Winger, 1972; Shell, 1972; Governor's Advisory Committee on Power Plant Siting, 1972.)

The current U.S. energy usage can be divided into five principal markets (Winger, 1972): industrial (32 percent), electric utilities (25 percent), transportation (24 percent), residential (14 percent), and commercial* (5 percent). These data are shown in Figure II.2A. Winger subdivides each of these market categories into finer segments and shows the trends, in growth rate and fuel sources of each subcomponent.

Alternative projections of future energy demand are currently available. One of the widely used projections is presented in Figure II.2B. This figure shows the total demand for energy, and the anticipated domestic supply from all sources. It refers to total prime energy and, according to other data, about a quarter of this will continue to go for electrical power generation.

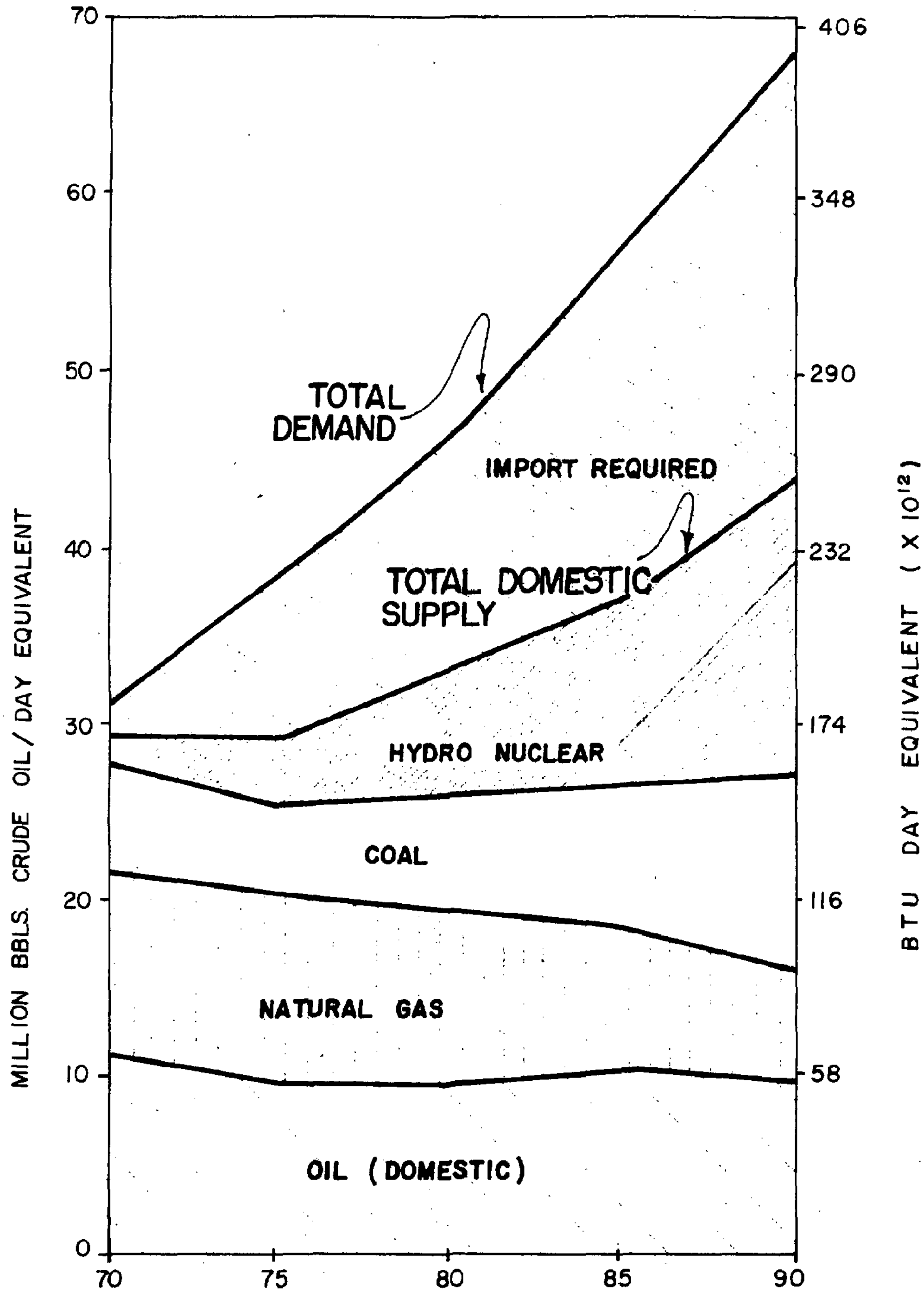
* All of these are markets for primary energy only; they do not show how electric energy (a secondary form) is used among the other sectors.



MAJOR U.S. ENERGY MARKETS

BASED ON 1972 DAILY CONSUMPTION OF 2.03×10^{14} BTU/DAY (OR 35×10^{6} BBL/DAY)

FIGURE II.2A



TOTAL U.S. ENERGY DEMAND, DOMESTIC AND IMPORTED (SHELL 1972)

FIGURE II. 2B

Figure II.2B indicates that domestic oil production will continue at about the present level of 10 million barrels per day; however, this assumes that all known reserves, including the Alaskan North Slope, will be used and that increased outer continental shelf activity will add significant new reserves. Natural gas is anticipated to decline; in fact, this decline already exists in many areas. The total contribution of coal is projected to almost double, from the 1970 rate of 34.8×10^{12} BTU/day to 63.8×10^{12} BTU/day. This prediction makes two rather significant assumptions: first, that the great coal fields of the western U.S. will be developed; and secondly, that widespread use of strip mining techniques will become more acceptable. The figure indicates a 10-fold increase in the combined hydro-power and nuclear energy sector. Essentially, all of the increase will be nuclear because there are few possible hydro-power sites remaining and most of those are not likely to be developed.

The great bulk of additional 1990 energy requirements would have to be met with imported supplies. While speculation is growing about liquified natural gas imports (LNG), most experts do not believe these will account for a significant percentage of the total U.S. energy demand. Thus, the only feasible alternative appears to be the importation of foreign crude, the great majority of which would come from the Persian Gulf--provided international politics permit. Figure II.2C shows the import requirement that will be supplied by overseas crude. The crude oil is almost certain to be shipped in a new breed of "supertankers" which are beginning to ply the world's oceans since these ships offer great saving over smaller, conventional tankers.

Natural gas currently provides the great bulk of the prime energy for electrical generation in the study area, and accounts for about a quarter of all U.S. generation output, has already peaked in the U.S. and is beginning to decline. Figure II.2D traces this rise and projected fall of U.S. gas production from 1955 through 1990. It also indicates possible future alternative sources for gas.

PROJECTED U.S. LIQUID PETROLEUM SUPPLY BY SOURCE

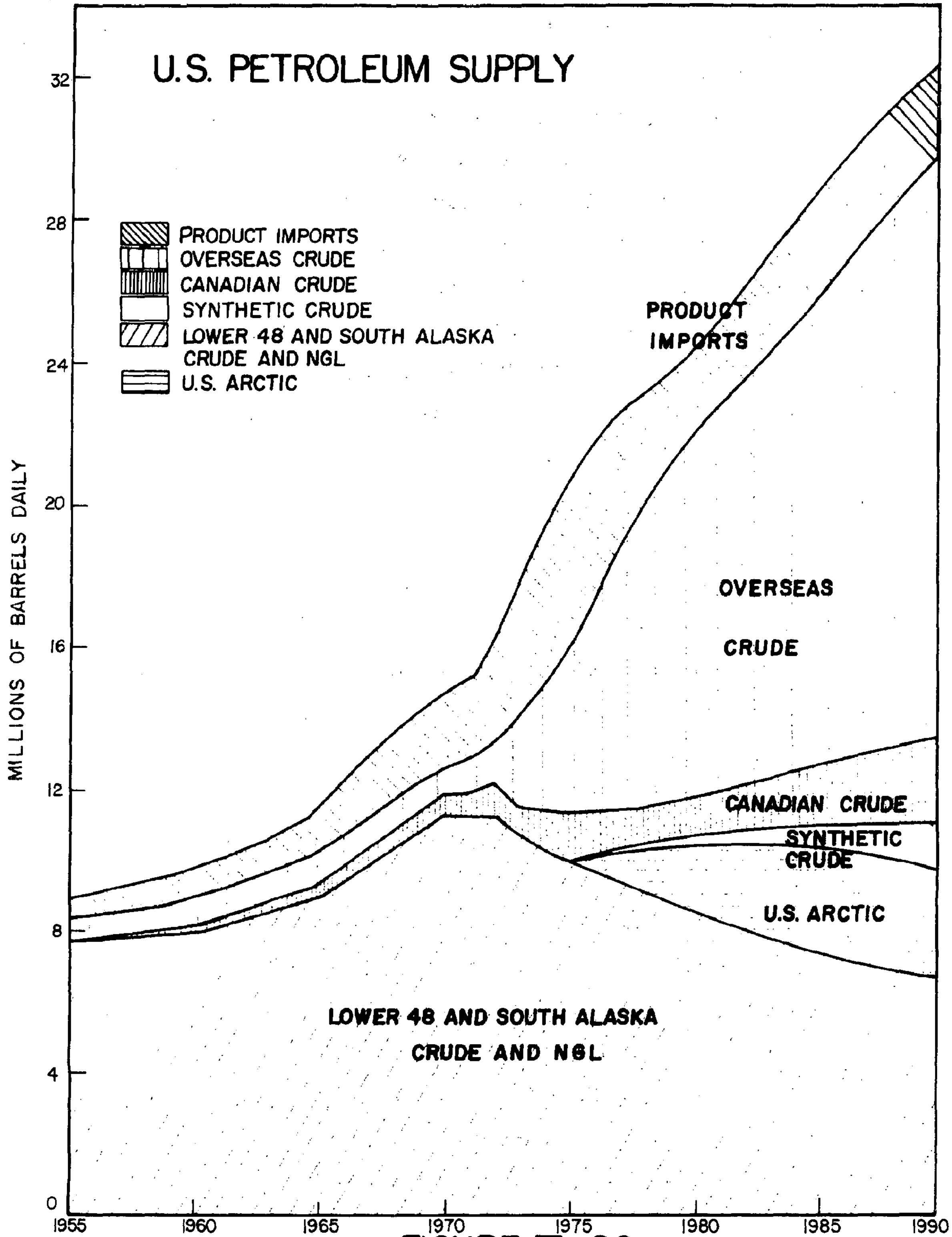


FIGURE II.2C

HISTORICAL AND PROJECTED U.S. GAS SUPPLY BY SOURCE

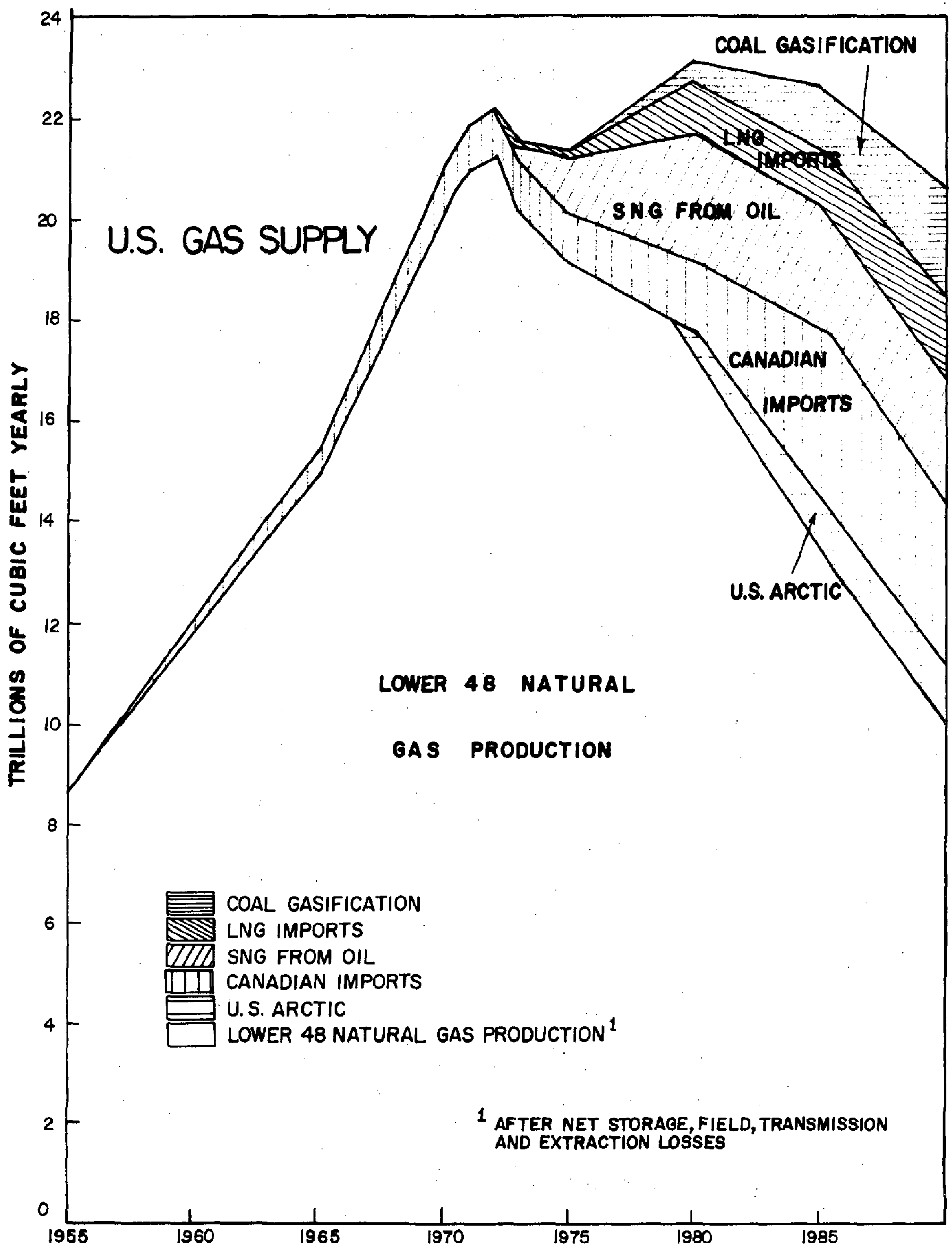


FIGURE II.2D

In investigating the national energy picture, Figure II.2D is a most significant illustration, highlighting a dilemma we are facing. It shows that the U.S. gas supply is going to decline; this strongly suggests that any new plants built in the study area will <u>not</u> be gas-fired. Combined with the rapid depletion of crude oil and the projected increased reliance on nuclear power, it follows that all new generating facilities that will be built to satisfy the study region's electrical demand are apt to be nuclear plants. This reliance on nuclear power is particularly significant when considering cooling aspects, because nuclear plants, for safety reasons, must be operated at lower temperatures and pressures than fossil fueled plants, and therefore at lower overall efficiencies.

Summary

This brief discussion of the national energy situation underscores the following points:

(a) The U.S. is entering a period when limited energy shortages are likely to be experienced by all.

(b) Industry and government are striving to increase our domestic energy production capacity, but decreasing domestic supplies make it increasingly necessary to rely upon imported energy sources for the future.

(c) Crude oil will form the bulk of the imports, although some LNG may be imported in limited quantities.

(d) While coal gasification and synthetic natural gas (SNG) may supplement domestic natural gas and LNG to a limited degree, the overall availability of gas will decrease; the resulting increased competition for the remaining gas supplies will virtually preclude the use of natural gas as a boiler fuel within the next decade.

(e) The costs of all forms of energy will increase; the increase will be passed on to the consumers.

II.3 THE U.S. WATER RESOURCE OUTLOOK

This country has experienced a long and aggressive history of water resource development and utilization. Most of the nation's major river systems have been dammed and developed for water supply, flood control, hydro-power generation, and navigation. Some of these major ventures include the Tennessee Valley Authority projects, the massive Mississippi-Missouri-Ohio waterway, and the Columbia River system. Associated benefits have been large water bodies for recreation and cooling purposes; an outcome, not as admirable, has been the availability of such waters for the deposition of liquid wastes. However, this latter situation is being eliminated.

Pressures Against Full Development of Water Resources

Without the development of its water resources, the U.S. could not have become the nation it is today. However, in the last ten years a new change in outlook has tried to reverse the trend which prevailed throughout the first 60-odd years of the Twentieth Century. Numerous organizations, spearheaded by concerned environmental groups have begun to question the continued need for developing and damming all the nation's rivers.

These opposition groups forcefully argued (1) such unrestrained development had irreversably damaged the natural environment; (2) in many instances projects had been promoted by certain special interest groups for their own immediate economic gain, with no consideration for the general public benefit, and this expenditure of large sums of federal funds for the actual profit of a few was most improper (this view was also shared by many consumer-advocate groups); (3) such projects, while they might generate much additional growth, might still not be in the best national interest because size could exceed the supporting capacity of our available natural resources; and (4) that certain parts of the natural environment should be left as they are, with the program for a national system of "wild-rivers" being derived from that feeling.

Other pressures have been superimposed on the public based environmental issues. Congress, in passing the National Environmental Policy Act (NEPA), has made it a national policy requirement that the environmental impact of all federally supported projects be determined and evaluated in comparison to their other benefits. This means, for example, that a project proponent can no longer justify a project solely on the basis of a benefit/cost ratio greater than one.

While "adverse environmental impact" has certainly caused some projects to be dropped by sponsoring agencies and resulted in others not being openly advocated, the real "key" in NEPA to stopping or at least to delaying projects has been a procedural tactic of using the courts. Anti-project forces have been most effective in obtaining injunctions based on the thesis that "a proper environmental impact has not been prepared". Thus, many projects have been effectively delayed or stopped not on the substantative grounds that they would significantly damage the environment, but on a procedural ground that not all the proper factors had been examined. Thus the search for answers has shifted from the hands of the scientists, engineers, and technicians and their laboratories and field investigations, and been put in the hands of the lawyers and the courts. This has been the real significance of NEPA.

Water policy and its role in the nation's future has also become controversial at the federal level. Ten scant years ago essentially all federal forces - Congressional and Executive* - were committed to continuing water resources

* The Courts were not significantly involved in any policy aspects because there was only one policy - "build"; the Courts, however, did have power on matters of land acquisition/condemnation, etc.

development; today the policies and outlooks are now quite diverse and frequently conflicting. Often the environmental/conservation-related agencies, including those charged with fish and wildlife management may openly oppose a project that is being promoted by other federal agencies such as the Bureau of Reclamation or the Corps of Engineers. The effect has been confusion and antagonisms resulting in delays or even cancellations of projects.

Federal water policy has been strongly affected and often pre-empted by federal fiscal policy, especially under the current administration. The basic thrust has been a change in federal cost-sharing policy which reduces, or even eliminates entirely, the federal support of a project. The Water Resources Council's principals and standards released in 1971 were a direct move toward the termination of federal support for water projects. The Office of Management and Budget, by impounding Congressionally appropriated funds, has in effect implemented such a policy through its control of the "purse strings".

In 1968, the National Water Commission was established and given the mandate to develop a comprehensive national water policy and report back to the President and the Congress in 1973. The Commission's report, (National Water Commission, 1973) has recommended the withdrawal of the federal government from water resource development, thus placing the financial responsibility for project funding on state and local governments. The Commission's recommendations have drawn both sharp criticism and strong support. In general, the feelings engendered by the report can be categorized in the following manner:

(1) Those interests supporting further water resource development either criticized or outright condemned the Commission's recommendations. This group included port and navigation interests, water supply/development agencies, river authorities, barge and towboat operators, irrigation

interests, etc.

(2) Environmental groups, consumer advocates and those favoring federal spending for urban problems, generally praised the Commission's report. The controversy spawned some strange bed-fellows: while most big business opposed the report, railroad and trucking quietly supported it.

At the national level there are major conflicts over whether water resource development should be done at all and, if it is done, how much, if any, of the cost should be borne by the federal government. In the past the power industry has often depended upon such multi-purpose public works to provide their cooling water; the implications then of significantly altering such policies become self-evident.

Increasingly stringent federal regulations on water pollution control present another important concern in terms of future heat-dissipation schemes for power generation. Pollution controls are apt to get "tighter" in the future, however vague they may be now. The current crackdown began in late 1969 when Congress passed NEPA and established the Environmental Protection Agency (EPA). This move served to consolidate the old "pollution control" agencies into one "super" department. EPA began to pull together and enforce the many federal pollution control laws. The most significant new development in water pollution control has been the Water Pollution Control Amendments of 1972 (PL92-500).

The 1972 amendments have many provisions; from the standpoint of the electric industry, the "zero-discharge" goal is the most compelling. The act declares it to be national policy to achieve "zero-discharges" of all pollutants by 1985, provided the technology is available to do so. The act is unclear as to whether or not an addition of thermal energy to a water body constitutes a "pollutant". What the possible ill effects of the thermal energy additions to the water body may be poses an even more fundamental question which should--but probably will not-- be answered first. There is no uniformally applicable answer.

In terms of the future, the implications of this uncertainty are profound. For example, planning and building new facilities that will have a zero-discharge in thermal energy to the receiving waters is technically conceivable, but highly impractical in terms of expense. Modifying all existing plants to meet this condition would simply be impossible. Some such plants could be modified with "add-on" cooling devices, but because of existing land uses, or water requirements, the majority would have to be abandoned and new plants constructed. The environmental assets to be gained from such actions are quite unclear, but it is certain that the economic penalties would be great. These cost increases, coupled with costs of new fuel supplies, could conceivably increase the cost of electric power out of all proportion to the rate of increase of the other components of living costs.

II.4 CHARACTERISTICS OF THE ELECTRIC POWER INDUSTRY

The electric power industry is one of the most unusual and diverse industries in the United States. While the many individual entities that generate and supply electrical energy do share many common problems, such as fuel supply and environmental control, they each have distinguishing individual characteristics. For that reason, any in-depth discussion of the electric power industry is far beyond the scope of this report; however, a few of the principal characteristics are central to this study and should be considered.

Utilities may be either investor-owned private corporations, special purpose public bodies, or part of a municipal government's public utilities department. All three of these exist in Texas. Since they all will be confronted by the same future growth and cooling alternatives, it is not germane to this study, into which of the three categories an electric utility might fall.

All are regulated monopolies which means that some public body is responsible for setting their rates. These rates allow the utility a reasonable profit after all expenses have been met. Texas is unique in that it does not have a statewide utility rate-setting commission. Instead, a utility must deal with each community within its service area and negotiates the rates on an individual basis. Regardless of how the rates are negotiated, any increased cost in power production and supply will be passed along to the consumer through increased rates. This means that in the future any thermal pollution control equipment that the utilities might be required to use will be ultimately paid for by the consumers.

A common characteristic of most utilities is that, as regulated monopolies, they are required by law to meet all power demands in their service area. If a customer says he wants a given quantity of electricity, the utility is bound to provide that amount. If the utility does not comply, then it may be taken to court. Utilities have often been criticized by environmental groups for promoting the increased use of electricity, yet the utilities' only alternative to expanding is to reverse their public relations efforts and try to discourage, rather than encourage additional uses and to promote energy conservation practices. Naturally, this requires substantial institutional adjustments and a profound shift in corporate thinking; essentially it amounts to "demotion" rather than "promotion" advertising.

The electric power industry has become highly sensitive about its public image, and with good reason. Its presence in virtually every home, office and factory insures that the "electric company" will not be forgotten or ignored. Most, if not all, electric utilities have been the frequent targets of both environmental and consumer interest groups.

All utilities fall under a wide variety of regulatory bodies at the federal, state and local levels. Federal activities are involved with safety and reliability, and increasingly with environmental concerns. State government's priorities are environmental protection, rate regulation (in all states except Texas) and, to a lesser extent, safety. Local governments are concerned with land use regulations, police protection, rate and, in many instances, environmental control, especially air pollution. This frequently complicates the utilities' operations. For example, there is no one place at any of the three levels of government that a utility can go to get a single permit or license to cover all aspects of siting and operation. Attempts have been made to establish such one-stop procedures, especially in the environmental field; however, many experts* feel that such efforts usually result only in one more layer of red tape rather than a simplification of the process.

Other problems facing the electric power industry, though not unique to that industry, include large capital investments, high interest rates, changing public attitudes and objectives, varying and often arbitrary regulations, diminishing fuel supplies, and rising manpower costs. Like other private concerns and public entities, the electric industry must continually strive to maintain its operation with the goal of providing acceptable service at the lowest reasonable cost to the customers.

<u>Summary</u>

The following points should be emphasized as crucial to this study:

(1) Increased costs as a result of pollution control measures will be passed on to the utilities' customers in the form of rate increases.

* Personal communications with utility personnel and governmental officials.

(2) Power generation capability will be expanded to meet projected demands.

II.5 CURRENT REGULATORY PRACTICES

The impression that emerges from trying to fathom the current practices of regulatory agencies is that they are "consistently inconsistent". New agencies are constantly being created in the environmental field: each new emergence alters the existing system, thus, inevitably, if not intentionally, changing some of the rules. This proliferation is occurring at the federal, state, and local levels. Although no new federal agencies have emerged since the Environmental Protection Agency (EPA) was created in 1970, new laws have been passed which change the ways the existing agencies operate.

This complex situation is further complicated at the federal level by (a) the lack of a definable, comprehensive national energy policy, (b) continued federal involvement in land-use management through the existing Coastal Zone Management Act of 1972 (P192-583) or as proposed in the National Land Use Policy and Planning Assistance Act (i.e. S268), and (c) the drive by many toward a "one-stop" federal agency for all aspects of power plant site approval.

At the state level the regulatory picture is generally no less complex. Many states have enacted mini-EPA's or passed state land-use legislation; almost all have some form of utility regulatory commission. In Texas, the institutional situation is somewhat simpler. Despite repeated attempts by environmental groups, no comprehensive state environmental agency has been established, nor has any land-use legislation passed. Texas, as previously stated, is also in the unique position of being the only state in the nation that does not have a utilities' regulatory commission. This means that when a utility proposes a new plant, it does not have recourse to an "all-powerful" agency from which to secure a license. Instead, the utility must get several independent permits from a number of separate, autonomous, and highly independent commissions, boards and elected officials. Different agencies provide approval for water rights, waste discharges, air emissions, intrastate gas rates, radiation safeguards, and the modification, if applicable, of state-owned public lands. The industry has shown a strong desire to keep the regulatory powers fragmented rather than move toward a more centralized state system.

The local regulatory situations encountered by the electric power industry are too varied to describe within the scope of this project. The fact that the regulatory practices vary greatly within a state as well as from state-to-state, and that such practices are apt to change rapidly with time, only compounds the problems. For example, a change over in a city council or county commissioner's court often results in a complete reversal of previous policies. Such an about-face can make life extremely difficult and uncertain for a utility planning program.

For the study area being considered in this report, such regulatory considerations are somewhat simplified by the following: (a) while municipal entities may change and wield significant land-use regulatory powers, all new plants are almost certain to be built well outside municipal limits, (b) county governments in Texas have few regulatory powers, and usually could not significantly interfere with a decision to locate a plant in an unincorporated area of a county, and (c) the general attitude of most local governments is strongly pro-development, and adverse reaction to any new power facility is not likely from this quarter.

The current laws, policies and administrative structure of governmental agencies tend to be fairly well suited for resolving conflicts between adversary positions. Unfortunately, these same arrangements, however, are not adaptive to the more demanding situation of developing creative, innovative approaches for fostering cooperation between the potential adversaries to develop realistic, feasible solutions acceptable to all involved.

This institutional shortcoming inevitably results in harsh feelings, name-calling, and often court action. The public may benefit by being "saved" from a given project that may have been against the public interest, yet the public often pays dearly in the long run for such decisions. Lost time, inflated costs, and a general feeling of ill-will, suspicion and reluctance among the adversaries to work together hurt future ventures, and leave deep scars.

If constructive cooperativeness is to be attained, several important conditions must be achieved, including (a) institutional changes which would provide a better opportunity to work together, (b) education of all concerned parties to improve mutual trust, and create a desire to cooperate for mutually beneficial purposes, rather than simply to "get the other side" and (c) the development of valid ecological and economic information upon which all parties can agree, and understand the trade-offs involved in controversial decisions.

The last of these three requirements is the objective of the report: <u>namely to develop a method for investigating the implications of environmental-economic trade-off and apply the technique to a regional power supply situation</u>.

II.6 THE NEED FOR AN ANALYTICAL APPROACH

By describing the present situation in the power producing industry, and the status of water resource development, some insights into future alternatives and solutions might be provided. The admirable goal of developing an orderly system for defining and analyzing options and trade-offs in the complex three-way triangle of "growth, energy and the environment", is a massive, if not impossible, undertaking within the immediate future, considering the information constraints in which we must operate.

An analytical approach, to be of real value in resolving the conflicts of this three-horned dilemma--growth, energy, and environment--must possess the following characteristics:

Condition I - Transformability - Rather nebulous policy statements, such as those found in legislation, must be transformed into quantitative alternatives. This quantification is necessary because "hard numbers" not "general philosophy" are required to trigger analytical techniques. This transformation is the most difficult step in quantitatively assessing the impact of public policy decisions on either the economy or the environment.

Condition II - Analytical Acceptability - The approach must be scientifically sound and generally acceptable to the experts in each field involved. Nothing can more quickly neutralize the validity of any given result than to have some noted authority point out that the procedure used in obtaining the result was in disagreement with some major theory or finding. Using techniques which command a maximum degree of acceptance is necessary. Sometimes such an approach means foregoing a latest development in favor of an older, proven technique.

Condition III - Interpretability - After the analytical gymnastics are completed, there must be a mechanism of translating the key numerical data back into information which is meaningful to the non-analyst. Essentially such a step is an inverse of the transformation required in Condition I. Unless the results are transformed into the general language of the original policy statement, the entire investigative process is almost certain to fail, simply because those who formulated the policy in the first place need an answer they can understand.

The need for a broad analytical approach which incorporates these three conditions may seem obvious. In the past, however, much analytical effort has been uselessly expended, while many public policies have been established and implemented without any serious analytical effort to evaluate their consequences. Indeed, the need to develop and use an acceptable assessment procedure is as necessary as it is obvious.

II.7 THE ANALYTICAL APPROACH

A generalized schematic diagram of the analytical procedure developed and used in this study is presented in Figure II.7A. The process begins with a formulation and quantification of alternative public policies, proceeds into an analytical phase, then culminates with an interpretation and presentation of the appropriate results. The six principal steps shown in Figure II.7A satisfy the three conditions shown in Table II.6A.

The analytical flow outlined in Figure II.7A consists of six principal steps with two sub-steps.*

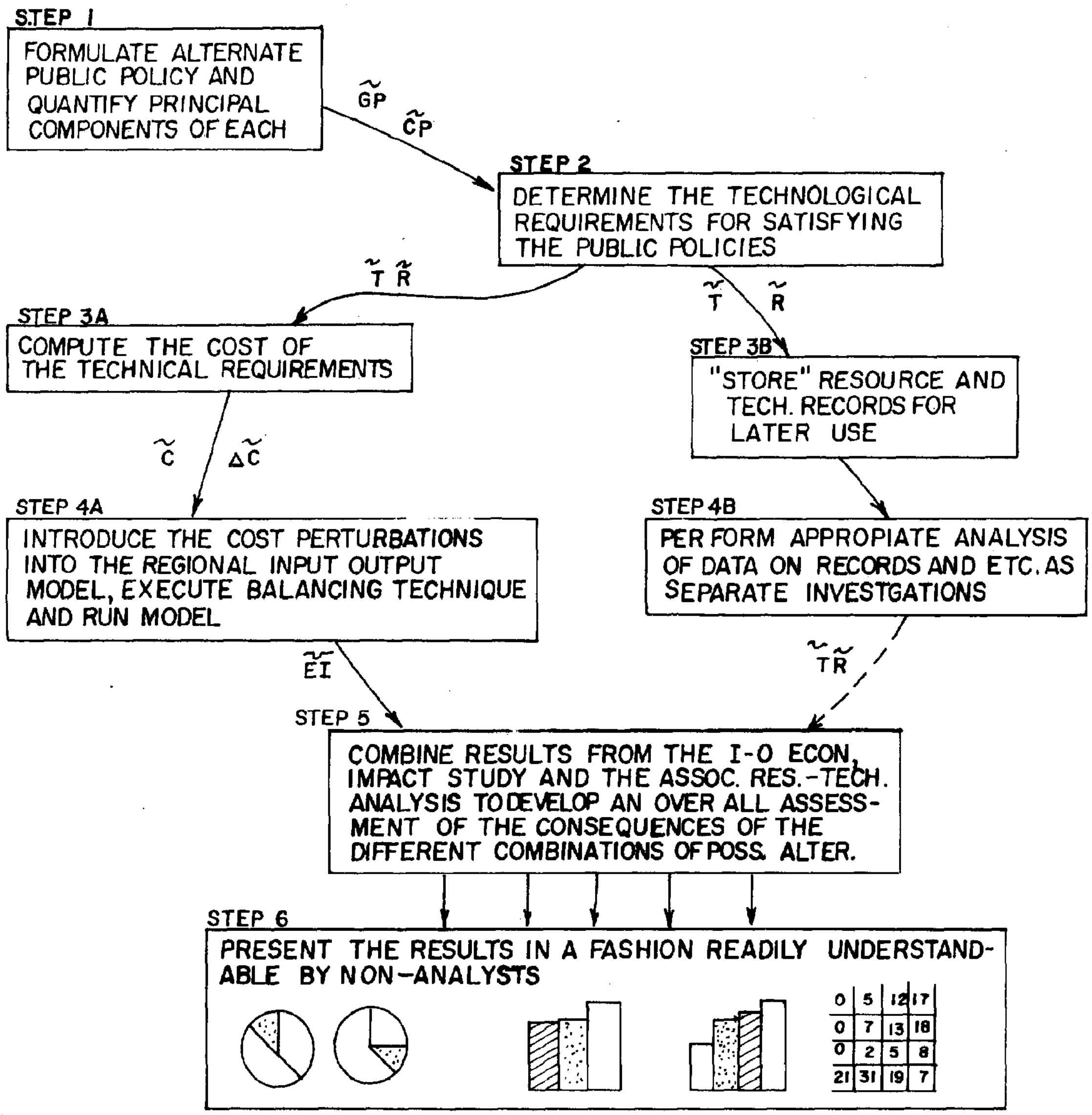
Step 1: Formulate and Quantify Alternative Public Policies - In this first step the public policies which are going to be studied are determined. Each policy is concisely defined, and the ranges of the policy are selected. Once the policy and the general boundaries are determined, the minimum, maximum and intermediate points to be studied must be quantified. In some cases, considerable study and ingenuity may be required to reduce a general public policy statement into quantifiable terms, but the task can be accomplished, either discretely or by a series of approximations.

* In developing and presenting this sort of information, it would be possible to use more resolution or less resolution. However, for explanatory purposes, this format was selected as being a good compromise between too much detail (confusing) and too little detail (vague).

CONDITION	COVERED IN STEPS
I. - TRANSFORMABILITY	1. POLICY FORMULATION AND DEFINITION
II. - ANALYTICAL ACCEPTABILITY	2. DETERMINE TECHNICAL REQUIREMENTS AND CONSTRAINTS
	3A. COMPUTE ASSOCIATED COSTS
	3B. HOLD RESOURCE AND TECHNICAL INFORMATION FOR SUBSEQUENT USE.
	4A. INTRODUCE COST PERTURBATIONS TO I-O MODEL, EXECUTE BALANCING AND IMPACT ANALYSIS TECHNIQUES.
	4B. EXTERNAL EXAMINATION OF RESOURCE REQUIREMENTS / TECHNICAL CONSTRAINTS
III. - INTERPRETABILITY	5. COMBINE RESULTING INFORMATION FROM PREVIOUS STEPS, SYNTHESIZE AND ASSESS THE OVER-ALL IMPACT AND RESULTS.
	6. PRESENT THE RESULTS IN A MANNER READILY UNDERSTOOD BY NON-ANALYSTS (IE PUBLIC OFFICIALS)

SATISFACTION OF THREE NECESSARY CONDITIONS BY PROPOSED ANALYTICAL PROCESS

TABLE II, 6A



GENERALIZED ANALYTICAL PROCEDURE

FIGURE II. 7A

Step 2: Determine Necessary Technological Requirements and Constraints - Once the public policy alternatives have been quantified, the method for best achieving the various policies' objectives while working within the constraints imposed by other policies must be determined. This second step, while requiring more technical/scientific expertise and computational effort than the first step, is apt to be conceptually simpler than policy formation because available technology is applied to meet explicitly stated conditions. The end-product of this step will be a series of technical alternative designs that meet the policy criteria and a set of resource requirements necessary to satisfy the technical conditions. For example, if ponds are to be used to achieve the necessary cooling, then relatively simple engineering calculations will determine how many acres of land area will be required for the pond.

Step 3-A: Compute Costs of Technical Requirements - Once the technical requirements are fully developed, the costs of each alternative can be computed, assuming that relatively specific situations are being considered. For example, if a given amount of land is required for cooling ponds, the approximate land prices in a locality can be obtained. For other technical requirements that are not as subject as land to speculative ventures, such as equipment, interest on capital, labor, etc., costs can be accurately estimated. Thus, the total cost of the pond system can be estimated.

Step 3-B: "Store" Resource and Technical Requirements - The costs of these technical requirements and additional resources computed in Step 3-A must be retained for later use. This information is particularly necessary when dealing with other resources which may themselves become critical limiting factors at some future date.

Step 4-A: Introduce Cost Perturbations into Regional Input-Output Model - The cost increases determined in Step 3-A are converted into a percentage change of the total electrical power cost. This change is then introduced as a percentage increase in each cell of the appropriate utility row of the input-output model. The input-output tables show transactions, i.e., sales and purchases, among the various sectors of the economy. These transactions are shown in terms of dollars spent (output) and dollars received (input). If the cost of the product or service in any row increases by a specified percentage, this increase must be distributed across the entire row. This series of changes will result in an increase in the purchases of all columns. Thus, a price increase or decrease may be introduced into one sector and, with the proper mathematical manipulations, the impact of the specific cost change can be traced throughout the entire economy. A careful scrutiny of the results by a person familiar with both input-output analysis and the specific situation being investigated is necessary to prevent an erroneous interpretation of the results.

Step 4-B: Perform Appropriate External Analysis of Technical and Resource Requirements Data - The resource requirements and the technical data developed in Step 2 provide a basis for the calculation of cost changes as computed in Step 3-A. These data also include information on land requirements, water consumption, water through-put, additional fuel requirements, etc. The significance of the data increases as the availability of other natural resources limits the options available to power system designers and governmental regulatory agencies. For example, a demand by certain interests to greatly reduce, or even completely eliminate the discharge of heated water from a plant into an estuary, would require fresh water cooling towers or dry cooling towers. If the plant were located in a "water-scarce" area with limited fresh water supplies, the first alternative might be eliminated, not simply on a cost basis, but because of the competing uses or possible adverse environmental effects from the construction of the dams and reservoirs necessary to provide the fresh water for the wet cooling towers. In the case of dry towers an equally unpleasant dilemma could result: dry towers require large amounts of additional energy for their operation, and as available fuel decreases such an alternative might become less desirable from the conservation standpoint, than was the warm-water discharge. Any real problem will reveal a number of other important auxiliary analyses which must be examined in order to make an investigation complete. This "secondary information" may exceed in importance the information being sought in the principal analysis.

Step 5: Combine Output from Each Element, Evaluate and Assess the Overall Consequences - Once the detailed economic impact results of the input-output analysis and the more general information from the resource/technical assessment are available, then a collective study of the two analyses is necessary. The various consequences of the different alternatives can be determined. Unfortunately there are no simple rules to follow. A meaningful interpretation of the collective results depends on the knowledge of the basic problem and related data, coupled with the ability of the analyst to identify and explain the significant relationships. In a "real-world" situation the amount of data generated will be overwhelming, which presents a challenge to the analyst's ingenuity to devise ways to identify the meaningful information without becoming bogged down in reams of numbers. Such an ability is probably more of an art than a science and comes only through dedicated effort and experience.

Step 6: Presentation of Results in Understandable Fashion - Once the analytical procedure is completed the "real" work begins. The ultimate value of an analytical study is independent of the quality of the problem definition and analysis. The analytical process has no power unless the results are used. Unfortunately, the results of most such ventures are never implemented, not because the results obtained are wrong, or too politically unacceptable to the decision-makers and policy setters, but rather because the analysts have failed to communicate with the top management responsible for implementation. A failure to present (i.e., market) the findings, results in the entire effort being shelved. To avoid this fate, simplified but realistic presentations with a maximum amount of graphics is recommended.

Simplified Example Using Six-Step Analytical Procedure

The example begins with the three basic known pieces of information shown in Figure II.7B. These data are as follows:

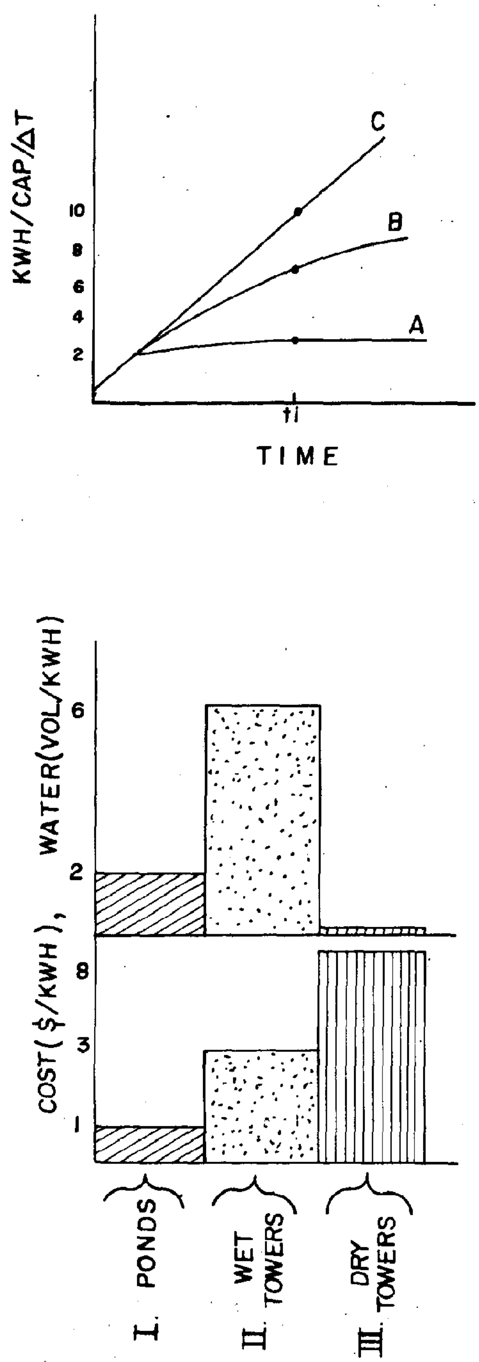
B.1 - Three hypothetical future demand curves showing the demand (KWH/cap/ Δt) for each of three forecast levels. For some future time, t, demands of 3, 7 and 10 KWH/cap will be used for the low, median and high projections.

B.2 and B.3 - Two principal characteristics, consumptive use of water and cost, for each of three cooling methods are presented for ponds (I), wet towers (II), and dry towers (III). The water use and cost data are given on a per unit basis - i.e., \$1/KWH or Gals/KWH.

Total water consumption varies from a low of zero for the dry towers which do not use water ($\overline{W}_{3j}$ j=1,3) to a high of 60 units for the maximum growth coupled with wet cooling towers ($\overline{W}_{23}$). Similarly, costs vary from \$3 ($\overline{C}_{11}$) to \$80 ($\overline{C}_{33}$).

The relative impacts on water resources become obvious by this point in the analysis. Costs are known; additional analysis is required to assess the over-all economic impact. Data, involving overall power cost and breakdown of utility sales are required to complete the analysis. These data are shown in Figure II.7D. The base cooling cost can be used to construct tables showing the possible range of water consumption and costs for each growth level and cooling option as illustrated in Figure II.7C. The water consumption for each alternative is determined by multiplying the amount of energy (KWH) required at any given level by the amount of water (Gal/KWH) for the particular cooling option. This procedure can be simply stated as:

$$\overline{W}_{ij} = (W_i) \cdot (E_j) \quad i = 1,3; \; j = 1,3$$



HYPOTHETICAL GROWTH LEVELS AND COOLING CHARACTERISTICS

FIGURE II. 7B

ARRAY OF POSSIBLE OPTIONS FOR TIME t

W_{ij}

GROWTH

COOLING OPTION(e) as water consumption W_{ij}	A (3)	B (7)	C (10)
I (P)	6	14	20
II (WT)	18	42	60
III (DT)	0	0	0

C.1

$$\frac{\text{COSTS}}{C_{ij}}$$

C_{ij}

GROWTH (P_j)

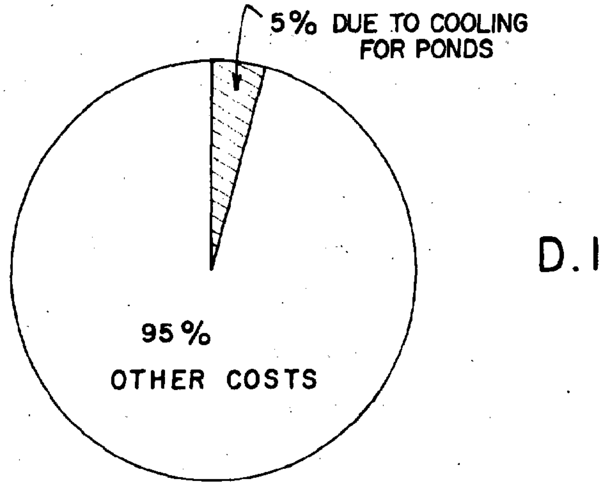
COOLING OPTION as cost, C_{ij}	A (3)	B (7)	C (10)
I (P)	1 x 3 $3	1 x 7 $7	$10
II (WT)	3 x 3 9	21	30
III (DT)	24	56	80

C. 2

$$\frac{H_2O\ \text{CONSUMPTION}}{W_{ij}}$$

EXAMPLE COSTS AND WATER CONSUMPTION FOR HYPOTHETICAL EXAMPLE

FIGURE II . 7C



BASE COST OF PROVIDING ELECTRICAL POWER

D. 2

D. 3

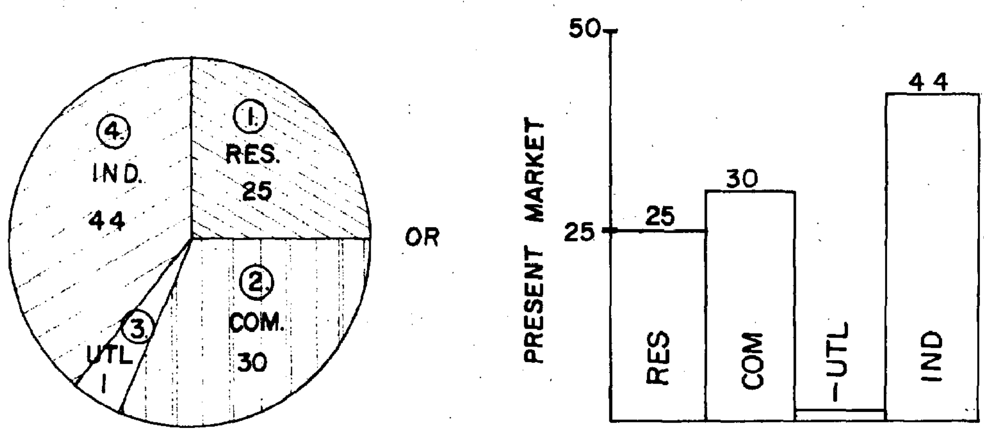


FIGURE II . 7D

where

$\overline{W}_i$ = total water consumed by an alternative (Gals)

W_i = unit water consumption of cooling method i (Gals/KWH)

E_j = energy requirement at growth level j (KWH/KWH)

i = cooling options, I,II, or III

j = growth level, A,B, or C

The various possible costs are constructed in the following manner using Figure II.7C.2:

$$\bar{C}_{ij} = (C_i) \cdot (E_j) \quad i=1,3;\ j=1,3$$

The cost of using ponds is assumed to be 5 percent of the total power cost. If the monthly electric bill is \$20.00, then \$1.00 is spent on cooling. Similar data are presented in Figures II.7D.1 and II.7D.2 and indicate the hypothetical breakdown of utility sales, namely:

RES (residential).	25%
COM (commercial).	30%
UTL (utility).	1%
IND (industrial)	44%
Total	100%

The costs of cooling options II and III would result in an increase in the cost of cooling and thus increase the total cost of electricity. This increase can be calculated by multiplying the base cooling cost percentage (5 percent from Figure II.7D.1) by the ratio of the modified cooling cost (II or III) over the base cooling cost (I), and then subtracting the original 5 percent.

$$\text{Option II (WT)} = \left(\frac{9}{3} \times 5\%\right) - 5\% = 10\%$$

$$\text{Option III (DT)} = \left(\frac{24}{3} \times 5\%\right) - 5\% = 35\%$$

Thus, if the base cost of power is taken to be \$1.00 with ponds (I), the cost increases to \$1.20 for wet towers (II) and is \$1.70 for dry towers (III).

A simplified four-sector transaction table is shown in Figure II.7E. The four sectors in this table correspond to the four groups shown in Figure II.7D, namely residential, commercial, utility, and industrial. Rows represent the sellers (output) and columns represent the buyers (input). Therefore, the utility's total sales of $20 (row 3) are distributed in the following manner:

residential	-	\$ 5.0 (25%)
commercial	-	\$ 6.0 (30%)
utility (self)	-	\$ 0.2 (1%)
industry	-	\$ 8.8 (44%)
		\$20.0 (100%)

Similarly the commercial sector's purchases are distributed as follows:

residential (wages)	-	\$ 3 (25 %)
commercial (self)	-	\$ 1 (16.7%)
utility (energy)	-	\$ 6 (50 %)
industrial (products)	-	\$ 2 (33.3%)
		\$12 (100.0%)

Commercial purchases are equally easy to obtain from the data in Figure II.7E.1. Note that some cells in the matrix contain only " - ". In a real input-output table these cells would contain numbers representing the transactions for the cell in question. No transaction would be shown by a zero entry. However, for this example these cells are blank to minimize the confusion.

Now the cost change resulting from the increase in the cooling component must be inserted into the utility row. From the data previously given in Figure II.7D.1, the cooling cost is 5 percent of the total cost for the base condition, Ponds (I).

The base cooling cost increases 10 percent in the total cost of energy for wet towers (II). Similarly, the cost increase for dry towers (III) would be

BEFORE (X_{32})

BUYER (INPUT)

SELLER (OUTPUT)	1	2	3	4	
1	–	3	–	12.5	
2	–	1	–	9	
3	.25 5	.30 6 .50	.01 0.2	.44 8.8 .176	1.00 20
4	–	12	–	20	
		1.00 12		1.00 50.3	

HYPOTHETICAL TRANSACTIONS TABLE BEFORE INTRODUCTION OF INCREASE IN UTILITY COST

FIGURE II. 7E

35 percent.

The procedure for distributing this increased cost is simple. If the total cost of all utility sales increases by a certain percentage, each component of the utility's sales is assumed to go up by the same percentage. If, for example, the total cost increases by 10 percent, each individual customer should expect his own bill to increase by 10 percent, regardless of whether he was a small or large purchaser. Mathematically this phenomenon is described by the following expression:

$$X'_{3j} = X_{3j} + kX_{3j} \qquad j=1,4$$

where

X'_{3j} = new value for cell j in utility row after the increase (\$)

X_{3j} = value for cell j before increases (\$)

k = increase in utility rate cost (percent)

j = columns corresponding to the four purchasing sectors.

The above operation is executed for both the 10 percent increase ($k = 0.1$) for wet towers and the 35 percent increase ($k = 0.35$) for dry towers. The results are shown in Figure II.7F.

The effect of a 10 percent increase is shown in Figure II.7F.1. Note that each value in each cell of row 3 is 10 percent greater than the corresponding cell in Figure II.7F. This matrix illustrates the result of distributing the 10 percent increase proportionally to each cell in the row.

Even more interesting information is obtained from row 2, the commercial sector. Electricity constitutes 50 percent of the purchase of this sector, or \$6 out of a total of \$12. If the price of electricity goes up 10 percent, the net electricity cost if \$6.6, thus the new column total becomes \$12.6. This change amounts to an increase of $\left(\frac{12.6 - 12.0}{12.0}\right)$, or 5 percent, in the total

F. 1

k=10%

SELLER (OUTPUT) \ BUYER (INPUT)	1	2	3	4	
1	–	3	–	12.5	
2	–	1	–	9	
3	5.5	6.6	0.22	9.68	22.0 (+10%)
4	–	2	–	20	
		12.6 (+5%)		51.18 (+1.76%)	

F. 2

k=35%

SELLER (OUTPUT) \ BUYER (INPUT)	1	2	3	4	
1	–	3	–	12.5	
2	–	1	–	9	
3	6.65	8.10	0.27	11.88	27.0 (+35%)
4	–	2	–	20	
		14.1 (+17.5%)		53.38 (+6.1%)	

FIGURE II. 7F

purchases of sector 2. Similar manipulations can be performed on the industrial sector purchases shown in column A which would show that a 10 percent increase in utility rates would cause a 1.76 percent increase in the cost of industrial products.

A similar examination of the data presented in Figure II.7F.2 reveals that the hypothetical dry tower case, which necessitates a 35 percent increase in electric rates will result in a 17.5 percent increase in commercial costs and a 6.1 percent increase in industrial costs.

According to the overall procedural guide presented in Figure II.7A, the first four steps of the process have been completed. The joint consideration of the results from the input-output analysis and the independent examination of resource availability, consumption and associated implications must be evaluated for each specific situation.

The above example, though an oversimplification, served to illustrate this method. The presentation of the analytical results in a manner readily understandable by decision makers is possibly the most significant step, and the most neglected. Refined, but simple graphics are an absolute necessity for this presentation. Two effective ways of showing the relationships among water consumption, growth (demand) level, and cooling method are illustrated in Figure II.7G.1. A much better simultaneous view of these relationships is represented in Figure II.7G.2. This three-dimensional plot is particularly valuable for assessing relative impacts of two different independent variables on a given dependent variable.

Results derived from the modified input-output tables of Figure II.7F are shown in Figure II.7H and provide a graphical indication of the added economic impact of the two cooling modifications--wet towers or dry towers--over the base option of ponds on commercial activities and industrial output.

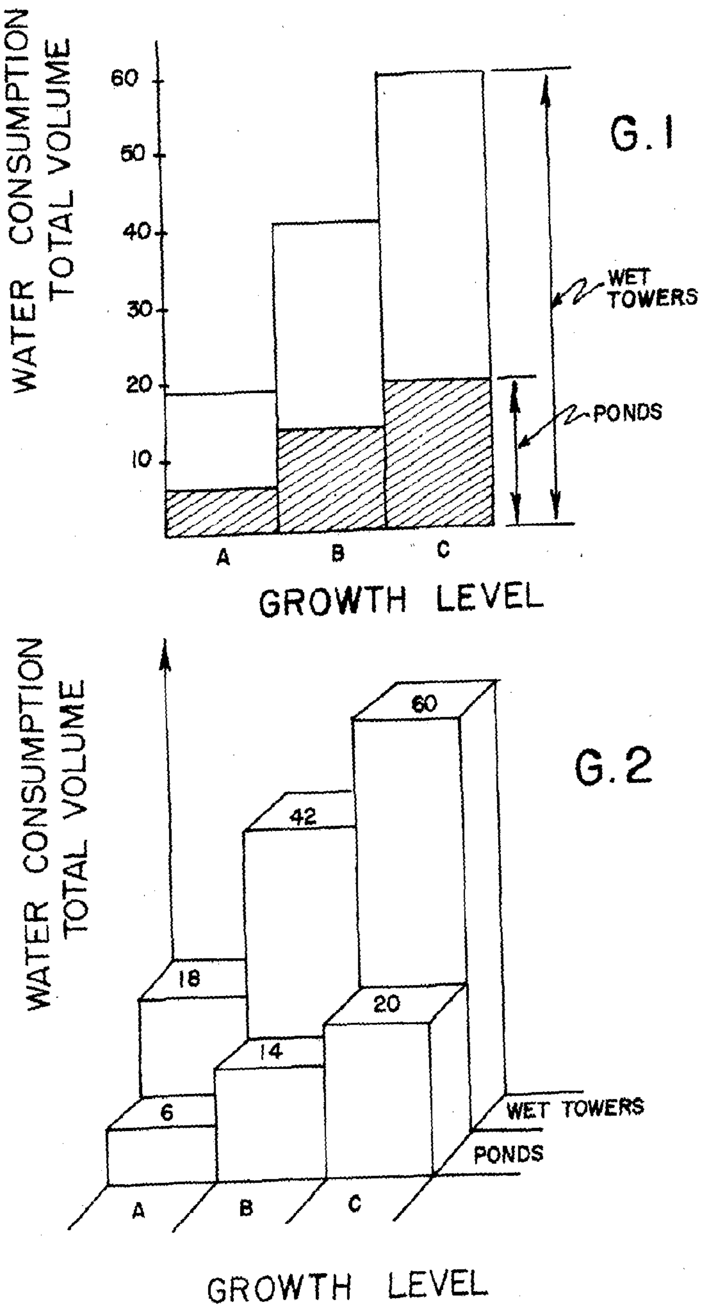

WATER CONSUMPTION
TOTAL VOLUME
60
50
40
30
20
10
G.1
WET TOWERS
PONDS
A
B
C
GROWTH LEVEL
WATER CONSUMPTION
TOTAL VOLUME
G.2
60
42
18
20
14
6
WET TOWERS
PONDS
A
B
C
GROWTH LEVEL

FIGURE II. 7G

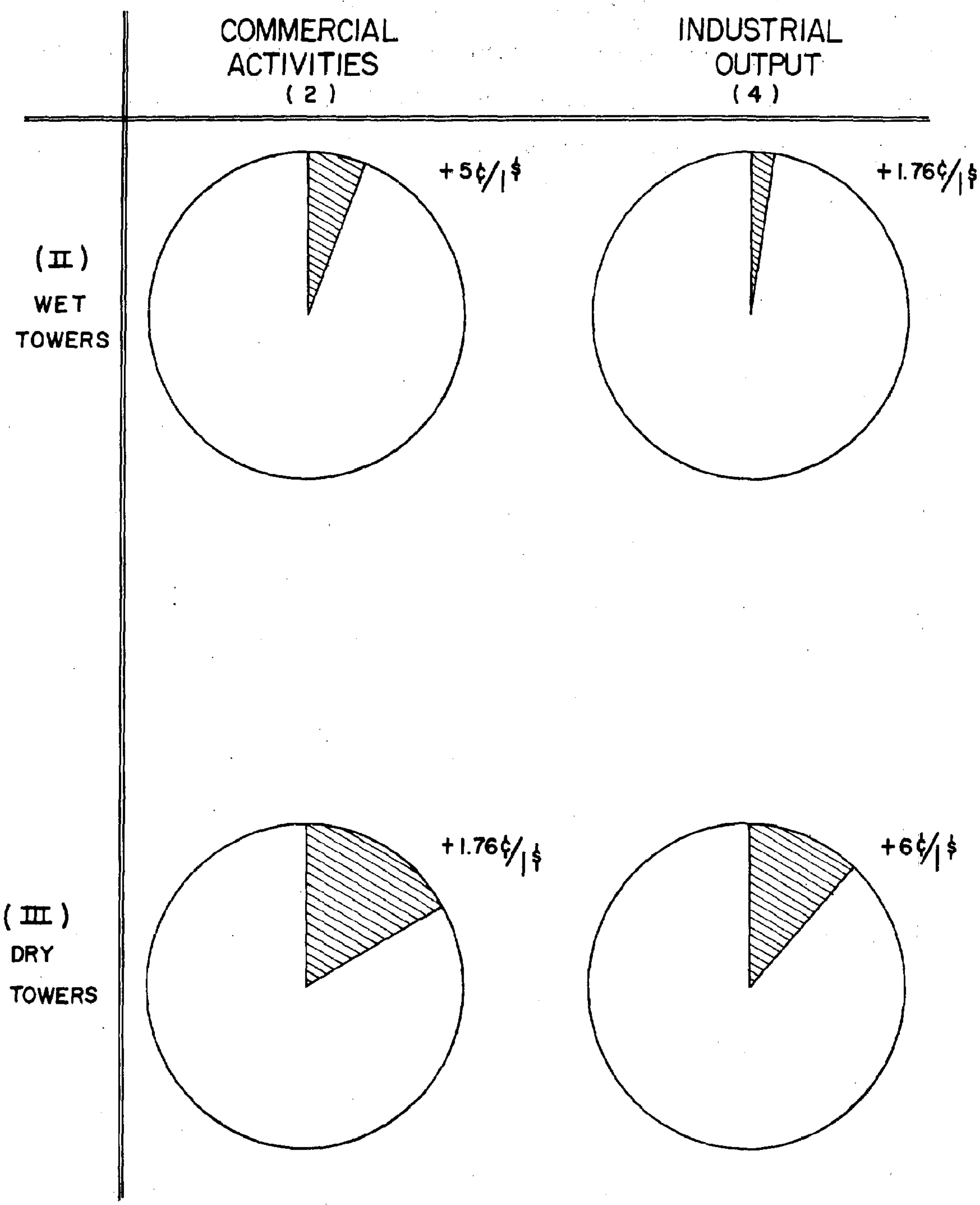

COMMERCIAL ACTIVITIES (2)
INDUSTRIAL OUTPUT (4)
(II) WET TOWERS
(III) DRY TOWERS
+5¢/1$
+1.76¢/1$
+1.76¢/1$
+6¢/1$

FIGURE II.7H

The above example has been deliberately kept simple to illustrate technique and make the procedure easier to follow, thereby preparing the reader to follow and understand the much more complex analyses presented later in this report. The procedures are the same, but the analyses are performed on complex 78 x 78 matrices with no voids, as compared to the special 4 x 4 matrices with 30 percent voids used here.

CHAPTER III

ALTERNATIVE PUBLIC POLICIES

In this chapter two policies, population growth and environmental protection, are subjected to the kind of analysis that was developed in Chapter II.

For the growth aspects, the total per capita energy consumption is held constant; the only growth variable is population. Environmental protection measures are restricted to waste heat disposal for power plants. These simplifications were made for the sake of technique development and demonstration; however, the approach is equally applicable to more complex studies. An additional benefit of such simplicity is that the results can be more readily interpreted by the non-analyst. Since one of the primary goals of this investigation is to make the facts more accessible to the decision makers and public officials who must eventually implement the public policies, such simplification is justified and even necessary.

This chapter traces the development of both the growth and waste-heat control (environmental) policies. It includes an explanation of the assumptions used in developing each set of policies, a presentation of the quantitative policy (i.e., numerical data), and a brief discussion of some of the implications.

III.1 GROWTH POLICY

Only a few short years ago, growth was a principal national goal; growth in all its forms: population, resource use, energy consumption, economic development, was synonymous with national progress. In the late 60's and early 70's, however, this general attitude began to change, and now many persons are questioning the old adage that says, "bigger is better". The recent decline in the U.S. population growth rate is one indicator of this change in attitude of many Americans.

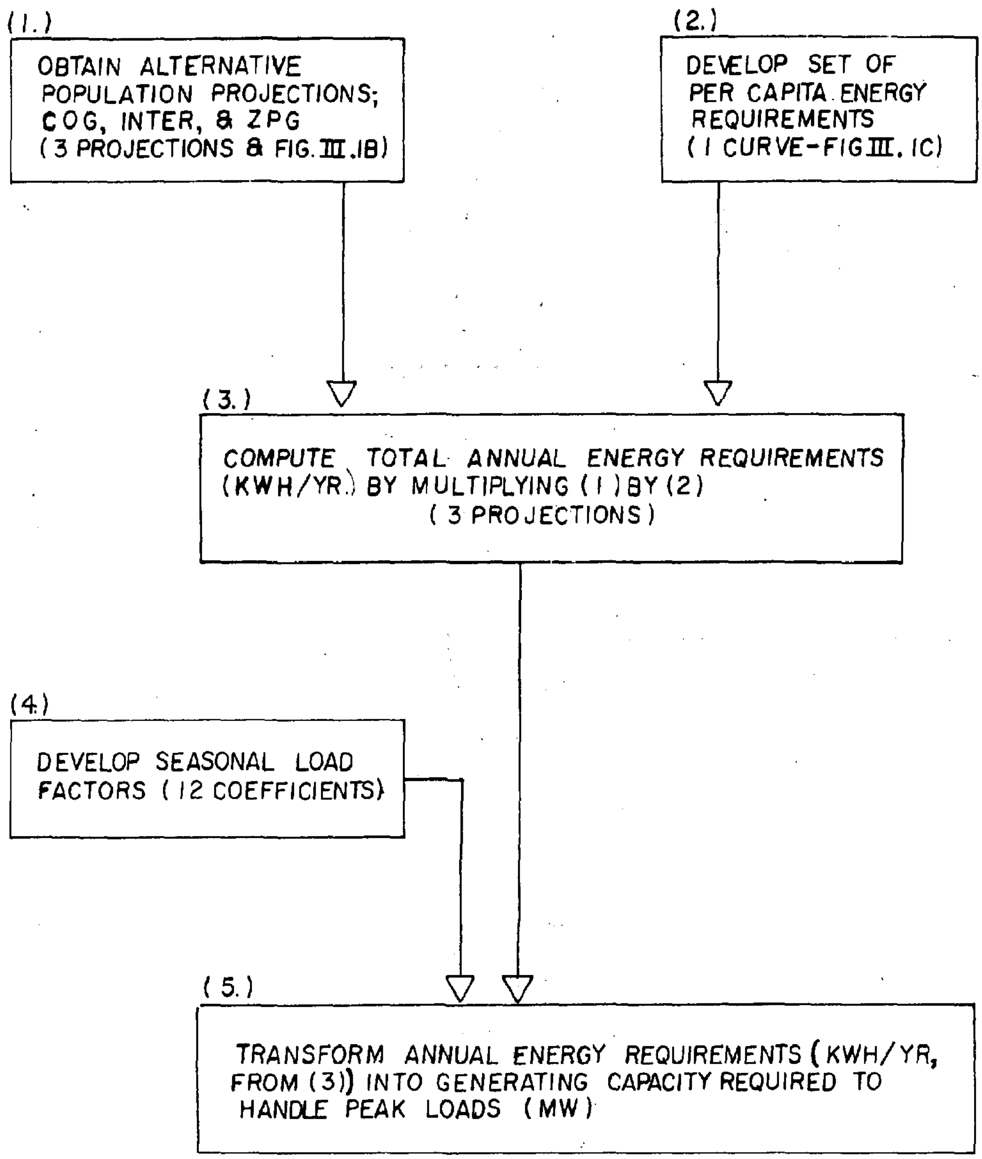
In this section, alternative growth projections for the future demand for electrical energy are developed. The total electrical energy demand is the result of many factors including population growth, per capita consumption, seasonal and daily demand variations, price, substitution of electricity for other energy sources, and changing socio-economic conditions.

For the purpose of this project, two growth figures are needed to compute dollar costs and resource requirements. They are (a) the total annual and seasonal energy consumption, and (b) the installed generating capacity required to meet the maximum instantaneous load placed on the system.

Several different approaches are available that could be used to develop the total demand figures. Figure III.1A is a simplified flow chart of the procedure used in this study to develop the projections. This procedure has five steps:

Step 1. Obtain three alternative population forecasts covering the study time horizon. These are given in Table III.1A and are shown in Figure III.1B as curves A, B, and C. Each is defined as follows: (a) A - Chamber of Commerce projection ("COC"), (b) B - Intermediate projection ("INTER"), and (c) C - Zero Population Growth projection ("ZPG").

The COC projection assumes that the region's population will increase 50 percent above the 1970 level by the end of the twentieth century. Alternative B, the intermediate projection, is based on the official state population forecasts issued by the Governor's Office. (Office of Information Services, 1972) The ZPG projection is based on the assumption that the population will increase another 10 percent and stabilize by the year 1985. Although many demographers



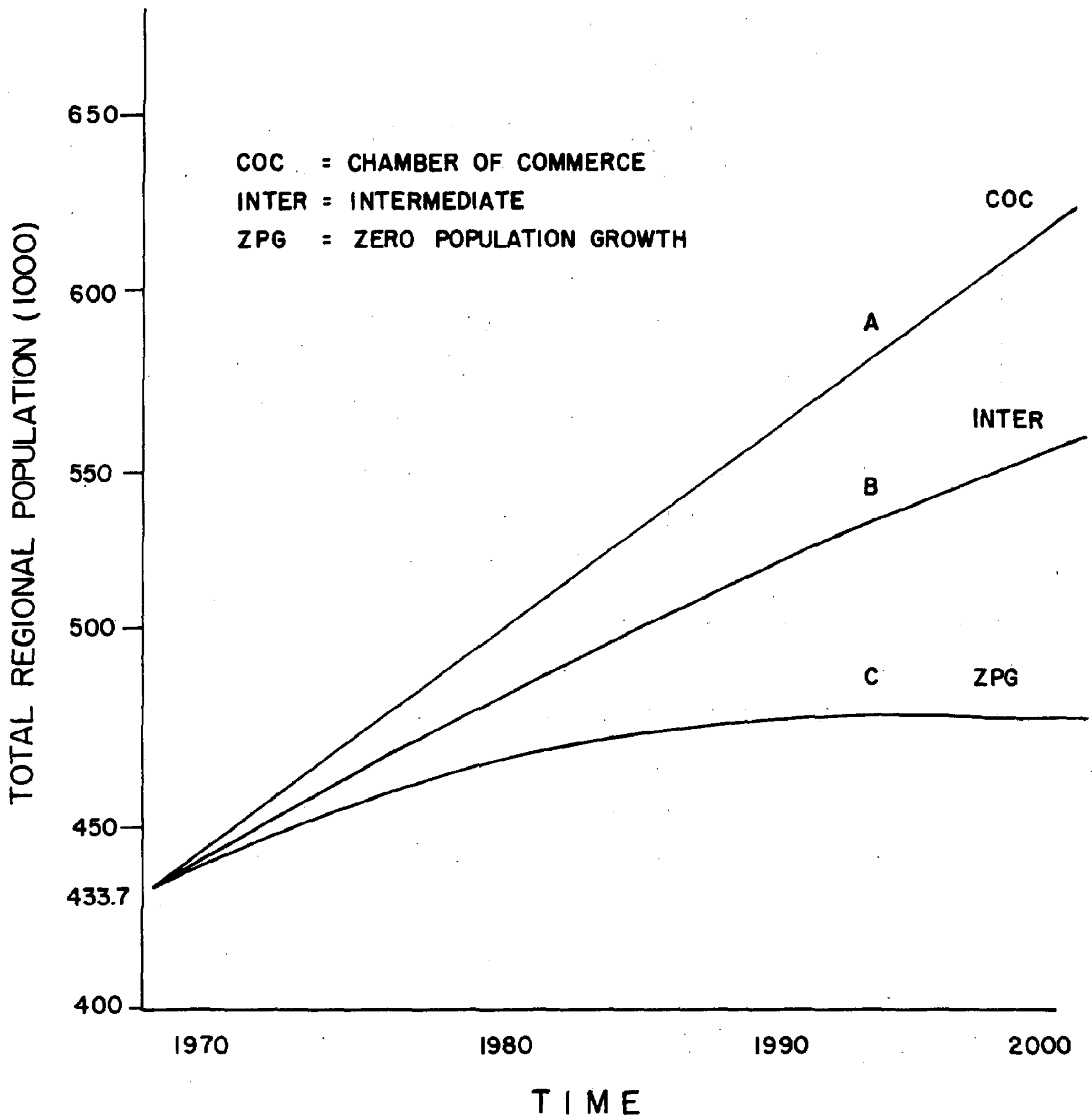
PROCEDURE FOR DEVELOPING TOTAL ENERGY AND PEAK LOAD GENERATING REQUIREMENTS

FIGURE III. 1A

	1970	1975	1980	1985	1990	1995	2000
ZPG		455,000	470,000	475,000	—	—	—
INTER	ACTUAL NO. 433,700	461,500	484,300	509,500	531,100	557,000	570,000
COC		470,000	505,000	540,000	576,000	612,000	655,000

ALTERNATIVE POPULATION PROJECTIONS

TABLE III. 1A



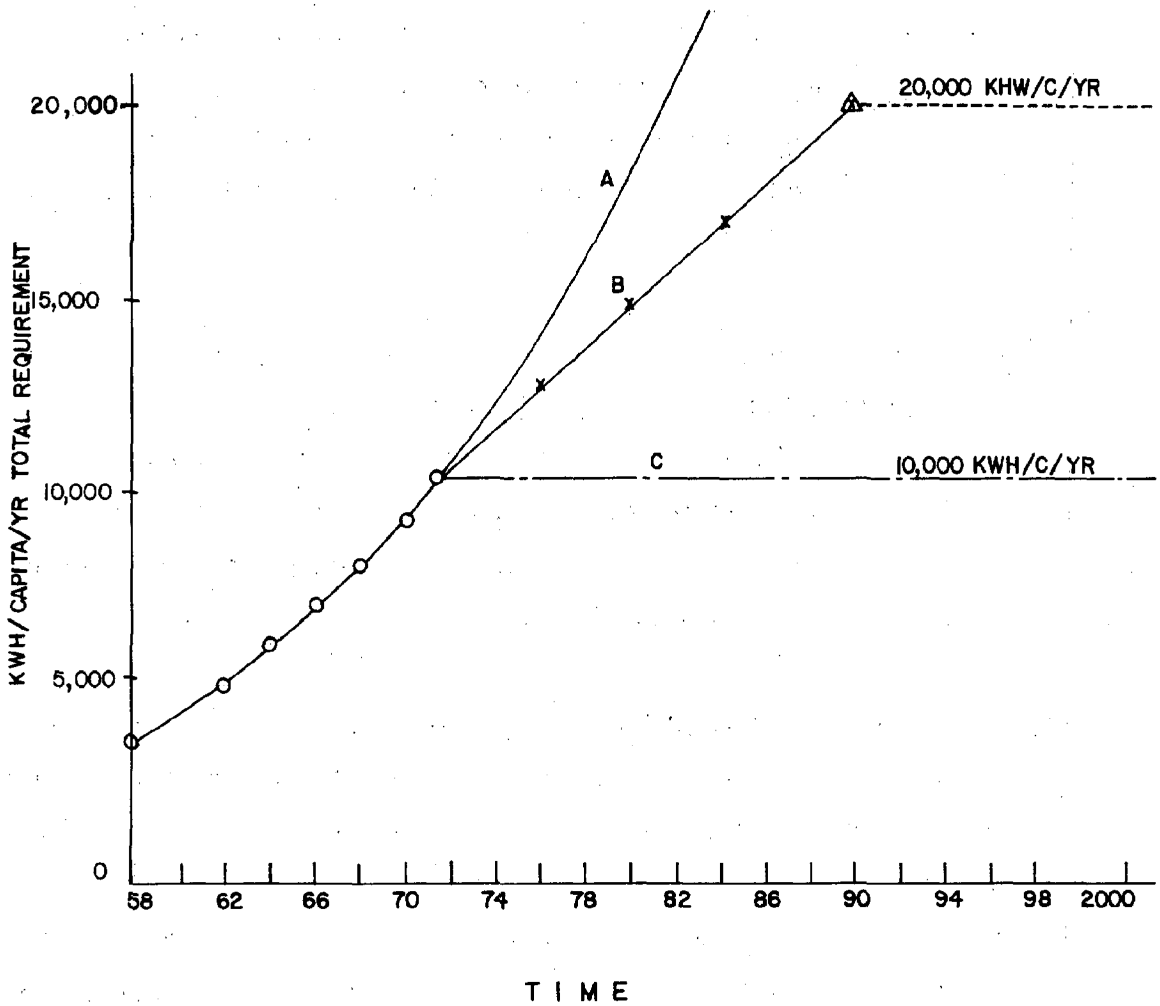
PLOTS OF ALTERNATIVE POPULATION PROJECTIONS
FIGURE III.1B

might consider these projections rather crude, the development of refined population projections is not one of this study's objectives, and therefore, for the purposes of the study, these data are as good as any. Any other set of projections could be incorporated into this analysis procedure.

Step 2. Develop a set of per capita energy consumption data. Figure III.1C shows the historical growth of per capita consumption in Texas from 1958 to 1971. (Governor's Advisory Committee on Power Plant Siting, 1972) This figure also shows three alternative predictions for per capita consumption through the year 2000. These historical data indicate that overall per capita consumption increased 160 percent between 1958 and 1970. In the one year period from 1969 to 1970, an increase from 8,795 to 9,410 KWH/CAP/YR, or an annual growth rate of approximately 7 percent occurred. For 1970 to 1971 these figures were 9410-10,180 for an increase of 8.1 percent.

Three future alternatives for the period 1972 to 2000 are postulated. The most conservative of these is an alternative that few persons would have thought credible even as recently as two to three years ago, namely a sudden leveling of unit consumption at current rates of approximately 10,000 KWH/CAP/YR. Because of fuel shortages and difficulties in power plant siting and licensing, this is now considered a real and desirable possibility. The most liberal projection assumes a continuation of the present annual growth rate.

The middle alternative shown in Figure III.1C is the above annual per capita consumption projection coupled with the population projections developed in Step 1, and used to compute future load forecasts. This projection is based on the following assumptions: (a) that the per capita consumption will double to 20,000 KWH/CAP/YR by the year 1990; (b) it will level off at that time and remain constant at 20,000 KWH/CAP/YR beyond 1990; and (c) the rate of increase will be uniform (an average of 5 percent per year) until that time. The selection of this projection is based on the two following premises: the per



ALTERNATIVE PER CAPITA ENERGY CONSUMPTIONS
FIGURE III.1 C

capita consumption of all forms of energy will remain about constant, but the shortage of other alternatives (in the study area this means natural gas) will force more and more consumers, including industrial and commercial users as well as residential customers, to convert to electricity. It would have been possible to use multiple levels in the same way as the population alternatives, but for the purposes of this investigation a single projection is adequate.

Step 3. Multiply the per capita consumption by the population to get total annual energy consumption (KWH/YR) for the region. These data are given in Table III.1B and shown in Figure III.1D. Even for the 1990 ZPG level, based on previously stated assumptions, requirements will increase from 4.08 billion to approximately 9.5 billion KWH/YR; for the COC case the increase would be to 11.5 billion KWH/YR.

Step 4. Develop seasonal load factors. From the annual energy consumption, the seasonal load distribution patterns are used to determine the generating capacity that will be required to meet the peak seasonal demands. Figure III.1E illustrates the typical seasonal load distribution patterns for the study area; 10.9 percent of the annual energy consumption occurs in the month of August, whereas February accounts for only 6.2 percent. Stated another way, the load factor is 1.76 for the month of August as based on 1.00 for February. The widespread use of air conditioning causes this pronounced peak during the summer months.

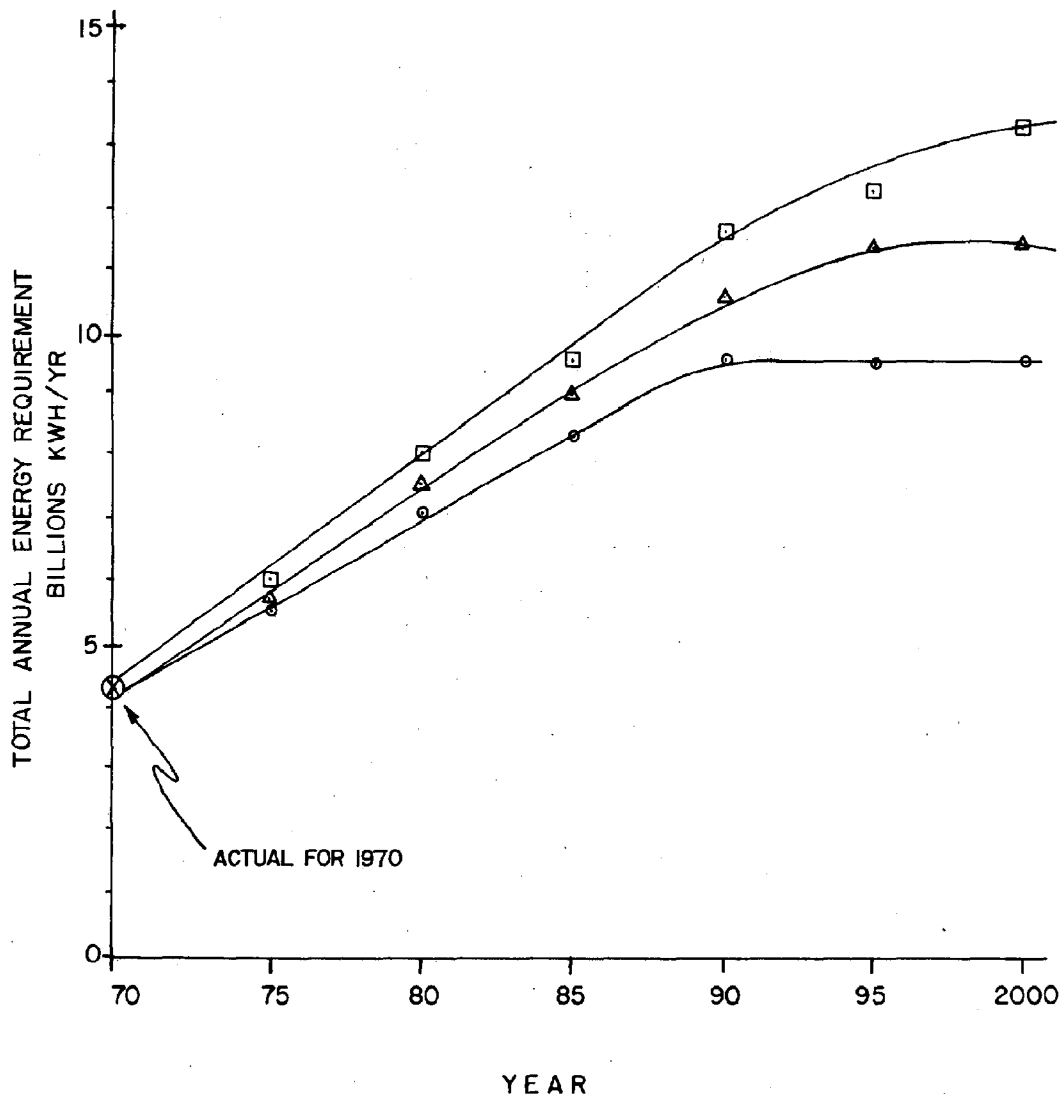
Step 5. Compute required generating capacity. Two options are possible in developing the relationship between annual energy requirements and the maximum required generating capacity. One method depends upon using seasonal load factors, hourly load factors, transmission distribution loss coefficients, required spinning reserves, "fudge-factors" for extreme weather conditions, etc., to synthesize a maximum probable instantaneous system

	ZPG PROJECTION		INTER PROJECTION		COC PROJECTION	
	EN. (KWH x 10^6)	GEN. (MW)	EN (KWH x 10^6)	GEN. (MW)	EN. (KWH x 10^6)	GEN. (MW)
70	—	—	4,081	1,682	—	—
75	5,550	2,300	5,630	2,300	5,730	2,400
80	7,050	2,900	7,270	3,000	7,580	3,100
85	8,310	3,450	8,920	3,700	9,450	3,900
90	9,500	3,900	10,620	4,400	11,520	4,750
95	9,500	3,900	11,140	4,600	12,240	5,050
2000	9,500	3,900	11,400	4,700	13,100	5,400

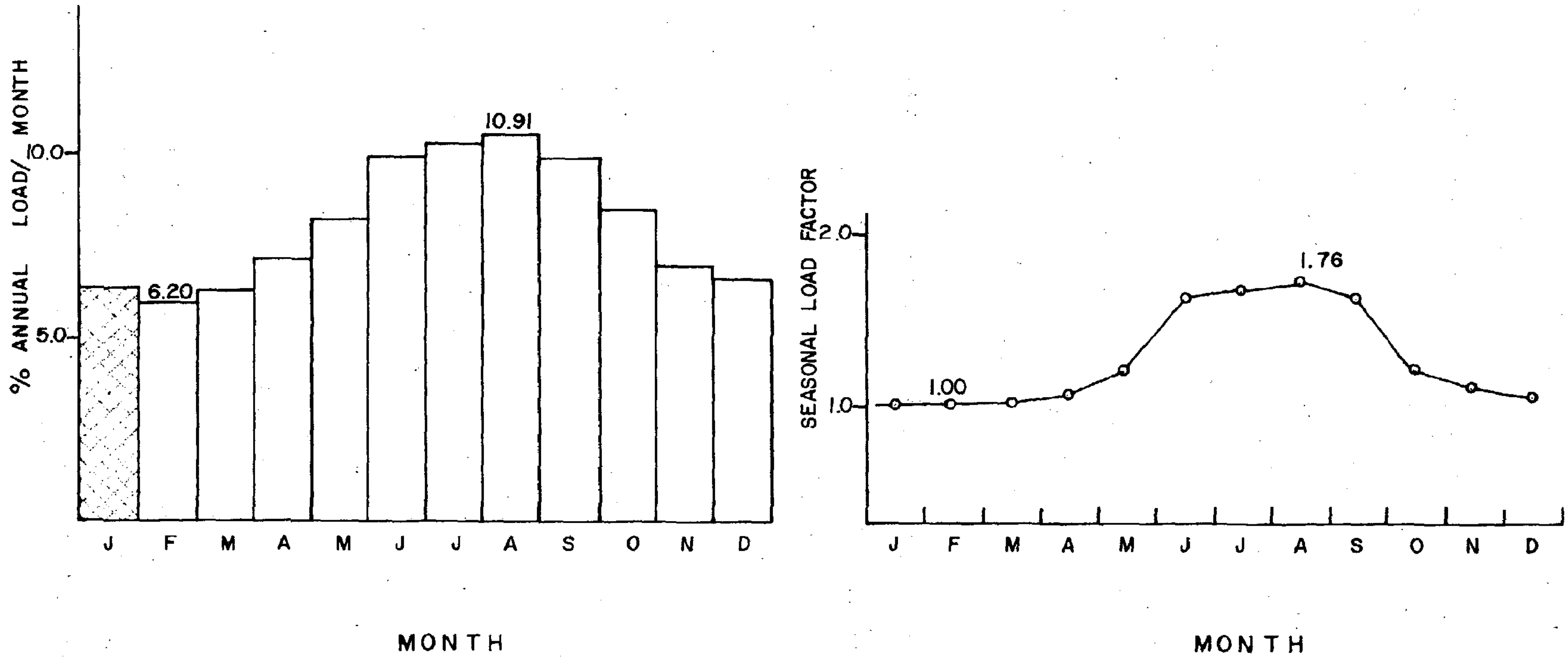
(1.) KWH PROJECTIONS ROUNDED TO THE NEAREST 10×10^6
(2.) MW PROJECTIONS ROUNDED TO THE NEAREST 50 MW
(3.) PEAK GENERATION CAPACITY (MW) = ANNUAL REQUIREMENT (KWH x 10^6) x MAXIMUM MONTHLY PERCENTAGE (0.1091) x 3.777 MW/MILLION KWH PER MONTH

PROJECTED ENERGY CONSUMPTION (KWH/CAP) AND REQUIRED GENERATING CAPACITY (MW) UNDER ALTERNATIVE GROWTH POLICIES

TABLE III.1 B



ANNUAL ENERGY CONSUMPTION
FIGURE III.1D



SEASONAL LOAD DISTRIBUTION

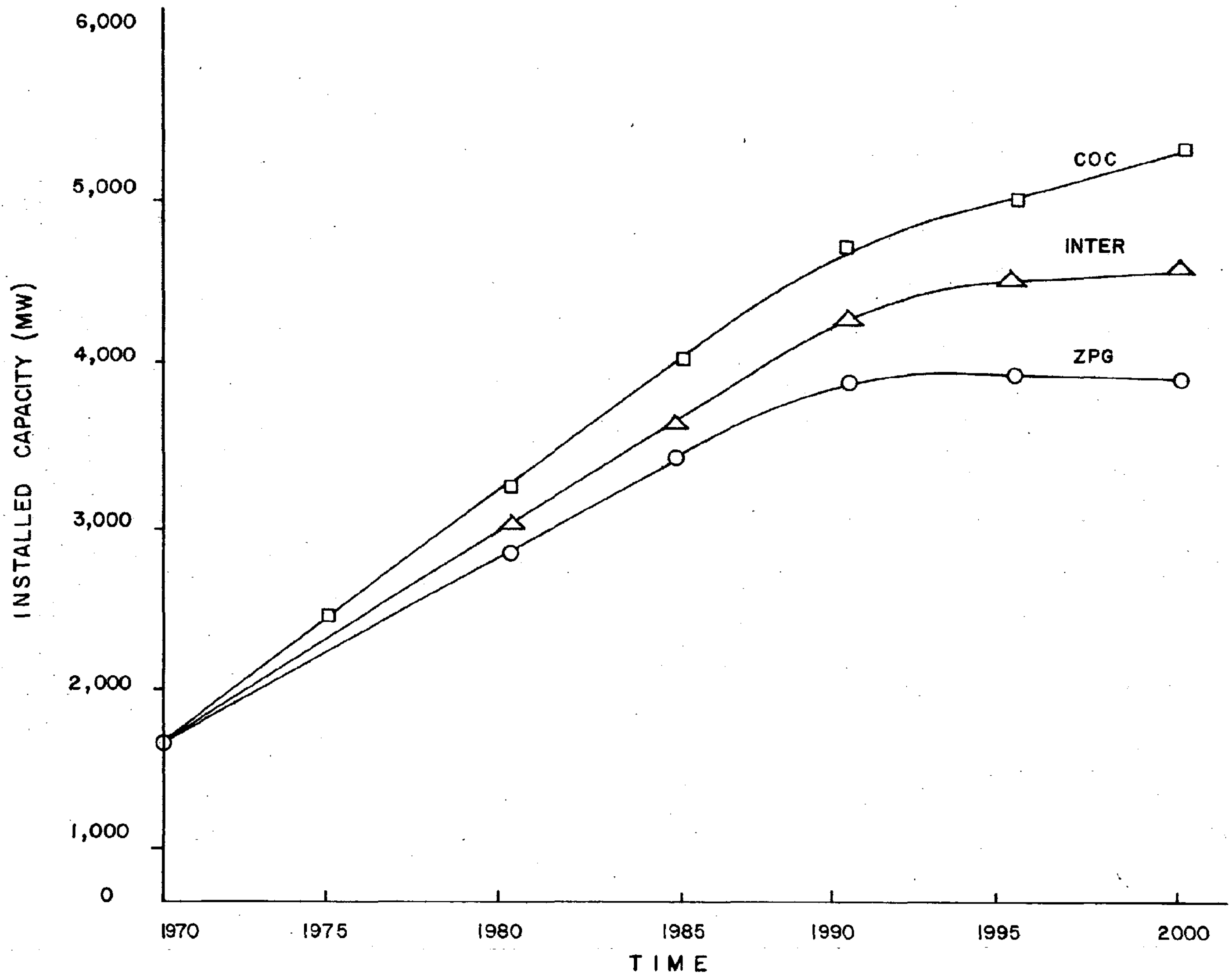
FIGURE III.1 E

load. This requires a large amount of actual system operational data.

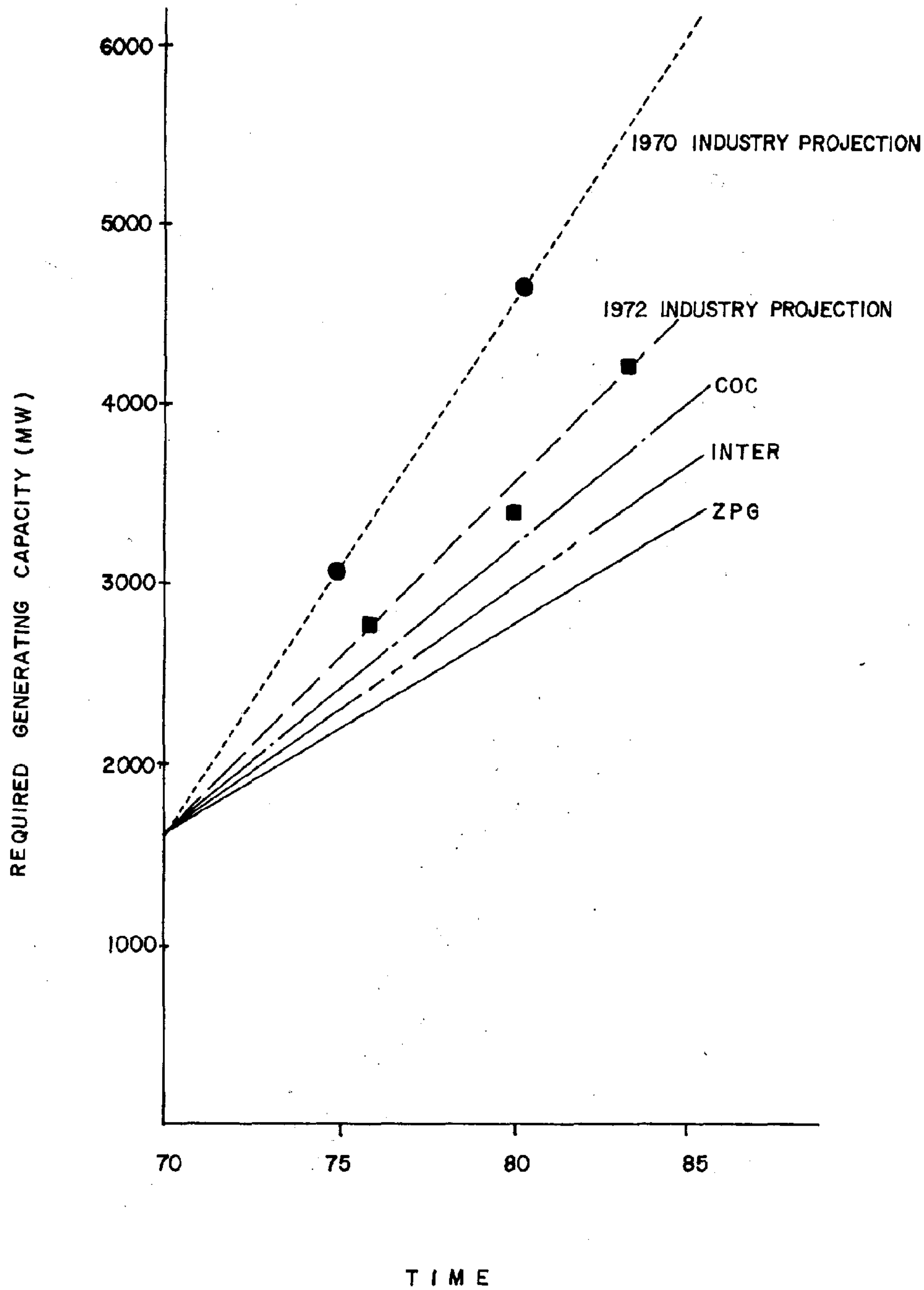
The other method is an empirical approach which correlates present maximum monthly demand to existing generating capacity and assumes this same relationship will continue in the future. This implicitly allows for all the factors mentioned under the first alternative. For the purposes of this project the latter approach was selected and used for the following reasons: its accuracy was sufficient for the objectives; it utilized the aggregated loss/reserve factors by tracking the current industry "best practice"; and this approach was much more straightforward and readily understandable. The required installed capacity data developed from this approach are given in Table III.1B and shown graphically in Figure III.1F.

It is worth carefully differentiating between the data shown in Figures III.1D and III.1F. The curves in III.1D reflect the total energy consumed over the entire year. These data, plus a fixed percent to allow for reserves and losses, are used to compute such long term resource needs as fuel consumption, land requirements, total water demand, etc. The data in III.1F reflect the probable maximum instantaneous load conditions that the system will encounter, and thus are used to determine the size and maximum capacity of the facilities.

A trend in changing attitudes toward growth and expansion is shown in Figure III.1G. The three lower curves are the projections developed for use in this study. The two upper lines are projections taken from reports published by the utility operation in the study area. (Personal Communications) Both projections were made by the same company, but done two years apart, yet there is a substantial difference in the two utility projections. In the 1972 estimates, the 1985 projected demand is about 25 percent less than the projected demand done in 1970. Both are higher than the COC projections, but if the apparent trend toward lower projections holds, the industry



REQUIRED INSTALLED GENERATING CAPACITY (MW)
FIGURE III . 1 F



COMPARISON OF PROJECTIONS FOR MAXIMUM REQUIRED GENERATING CAPACITY

FIGURE III.1 G

forecasts and synthetic projections developed for this study will soon coincide.

The following points should be emphasized.

(1) The projections for future growth in power demand are based on numerous assumptions of population growth, per capita energy usage, etc.

(2) Although these growth projects will be used in subsequent computations, any other set or sets of projections could be used equally well.

(3) When assessing different parameters, it is necessary to carefully differentiate between total energy consumed (III.ID) and maximum system capacity (III.1F).

III.2 ENVIRONMENTAL CONTROL POLICIES

Many types of environmental control devices and procedures are associated with a modern power plant. They include devices to deal with air pollution, water quality, and in the case of nuclear facilities, radiation; other more subtle considerations involve noise and visual aesthetics. In the National Academy of Engineering's report on power plant siting (National Academy of Engineering , 1972) there is a good summary discussion of the various environmental controls of modern power plants.

Our investigation concerns itself only with the waste-heat disposal aspect of powerplant environmental control. The objectives of this report are limited to evaluating the impact of cooling alternatives and growth levels.

To determine just what might constitute a reasonable, i.e., "expectable" set of future conditions for waste heat disposal, a preliminary investigation was done to evaluate the current situation including recent trends, regulatory action, and the stated goals of recent federal water pollution control legislation. The views and opinions of a number of prominent individuals, representing all interest groups were solicited. Several studies which had evaluated the economic impact of alternative levels of pollution control were reviewed. From studying all these sources the following conclusions were drawn:

(1) The pressures to eliminate thermal discharges from steam-electric power plants will continue, and in most instances much stricter waste-heat discharge constraints will be imposed.

(2) As a result, few, if any, new facilities will be built with once-through cooling on rivers and estuaries.

(3) Most existing plants will probably be allowed to continue operation in their present state; however, there may be some specific cases where damage due to waste-heat will be proved. Some sort of supplemental cooling will then be required.

(4) There will be a general impetus to use cooling towers, although cooling ponds will be acceptable in certain cases.

(5) Proponents of dry towers will continue to grow, but because dry towers require considerable energy to operate, their widespread use in the near future is likely to be inhibited.

(6) While there will be some supporters of deep-ocean outfalls and offshore floating plants or artificial islands, many obstacles, including both environmental objections and international law uncertainties, still exist.

Three alternative waste-heat disposal policies follow from these considerations. By combining them with the three growth policies presented in the previous section, nine "alternative futures" are created.

Before presenting and explaining the three waste-heat-management policies, two other studies that have investigated the costs of various cooling policies, should be considered. Both studies involved the development and analysis of "alternative futures" as used in this study.

One study, "A Systems Analysis of Aquatic Thermal Pollution and its Implications", (Cheney and Smith, 1969) was done for the National Coal Policy Conference, Inc. It had the following objective:

> "...provide a broad system overview...highlight the considerations that must enter the systematic appraisal and evaluation of the problem..."

The estimation of cooling costs and the appraisal of the cost implications on both the industry and consumers were two significant elements of that study that are of consequence to this investigation.

The cost portion of the study included an estimate of thermal pollution abatement costs to 1980. In attempting to estimate these costs, one of Cheney and Smith's first steps was to postulate three possible strategies that might be imposed by regulatory agencies*:

(1) "Pristine Purity" - Under this condition, all steam-electric plants, both those already in operation as well as all new facilities, would be required to eliminate heated water discharges.

(2) "Nondegradation" - In this case, all new facilities would have to eliminate heated discharges, but existing plants could continue their operations as they are now.

(3) "Practical Maximum" - This case is more complex, but Cheney and Smith view it as more realistic than the other proposals. It

* The report was published in January, 1969; the work was done in 1967-68 which was before the recent enactment of numerous environmental laws by the Congress and the various states.

has three assumptions:

(a) one-third of the new units and one-fourth of existing units would eliminate heated discharges;

(b) an additional one-third of the new units would be able to meet abatement requirements at 50 percent of wet tower costs; and

(c) the remaining units, both existing and new, would be exempted from controls involving appreciable costs because of favorable local circumstances.

Another study done by the Federal Power Commission (Warren, 1970) is also based on three assumptions concerning future restrictions on heated water discharges:

(1) "A" assumes that each plant will use the cheapest cooling system which causes the least "physical intrusion" on the environment, provided there is no violation of approved local criteria. For example, if sufficient natural flow were available to restrict significantly raised temperatures to a reasonable mixing zone, once-through cooling would be used. If this were not possible, then ponds would be the next alternative; and if for some reason, such as lack of land, ponds could not be used, then cooling towers would be used.

(2) Condition "B" assumes that either a pond or tower would be required on all new plants, unless it were possible to use a long-ocean outfall. All existing units would be left as is.

(3) Assumption "C" would require that all plants, regardless of when they were built, would be required to use ponds or towers unless a long-ocean outfall were possible.

The approaches taken by Cheney and Smith and Warren seem realistic, even though they were formulated several years before the National Environmental

Protection Act was passed or the EPA was established, and predated by more than four years the passage of the 1972 Water Quality Act Amendments. Also, since the late 60's a number of states have significantly tightened up their water pollution abatement program. The national attention within the last year has been focused on the pending energy crisis; this may ultimately cause the loosening of environmental protection constraints--at least in some localized situations.

Even though both sets of projected conditions were made for the entire nation and were therefore based on national trends and nationwide averages, their assumptions provided valuable background material in developing the alternative futures for this project. Several different sets of assumptions were considered in this study. The objective was to devise three possible cooling policies which would span the entire range of possible choice, from liberal to extreme. After several possibilities were explored, the three following cooling water policies were selected as most representative:

(1) Cooling Option A (C_1) - Continue present practices, subject only to meeting localized discharge criteria. While various interpretations of this policy are possible, for the purposes of this analysis, it is assumed that once-through cooling, either salt or fresh water, will be permitted on new facilities and that all existing plants may continue to operate as they presently do.

(2) Cooling Option C (C_3) - This is the other extreme from option "A". It would constitute strict interpretation of the zero-discharge provisions in the 1972 Water Pollution Control Act Amendments. This would mean that, by 1985, any water discharged by any power plant would have to be cooled to its initial input temperature. This would necessitate the removal, by supplemental cooling techniques, of all BTU's added to the water during its passage through the condensers. This would apply to both new and existing plants.

(3) Cooling Option B (C_2) - This alternative would "freeze" the total heat discharge (BTU/day) at current levels. It would be left up to the utility to determine how to allocate this allowable load among existing and new plants. No individual discharge would be allowed to exceed existing local criteria, and this would impose an added constraint. While meeting these local standards might pose some non-trivial problems for the utility, the overall regional incremental cooling cost would be about the same regardless of what specific trade-offs might occur on these individual decisions, because on the whole, the utilities would meet the environmental requirements in the least expensive manner.

These three environmental control options are certainly not all inclusive, but they are logical and sufficient for the purposes of this project. The following four points substantiate this contention:

(1) They cover the entire spectrum of probable alternatives.

(2) They are easily explained and readily understandable to both public officials and the general public who may not be familiar with the situation.*

(3) These three general verbal policy statements can be easily "quantified" and used as numerical input to trigger the analysis procedure.

(4) The three policies are different enough so that once they have been quantified and analyzed, the different implications of each can be readily seen by the non-analyst.

Table III.2A presents a brief summary of the three cooling policies with some important features of each. In the next section these cooling projections

* While this may seem relatively unimportant to some, this concern for acceptibility and simplicity cannot be overemphasized; unless this condition is met, the entire effort to utilize high technology in public-body decision-making will fail.

COOLING POLICY	ACCEPTABLE TECHNIQUES	PLANTS AFFECTED	DOES IT SATISFY EXISTING FEDERAL LAW?
C_1 - CONTINUE TO ALLOW ONCE-THROUGH BUT DO NOT VIOLATE LOCAL TEMPERATURE STANDARDS	ONCE-THROUGH PONDS TOWERS (W & D)	NEW ONLY	NO
C_2-FREEZE TOTAL BTU RELEASE AT CURRENT LEVELS. PERMIT ALLOCATION OF ALLOWABLE BTU's AMONG NEW AND EXISTING FACILITIES, PROVIDED, HOWEVER THAT NO LOCAL STANDARDS ARE VIOLATED.	LIMITED ONCE-THROUGH PONDS TOWERS	MOSTLY NEW, BUT SOME EXISTING ON TRADE-OFF BASIS	PARTIALLY
C_3-ZERO WASTE HEAT DISCHARGE TO BE REQUIRED BY 1985 OF ALL FACILITIES.	SOME PONDS-WITH SPRAY SUPPLEMENTS TOWERS	ALL - BOTH NEW AND EXISTING	YES

SUMMARY OF ALTERNATIVE COOLING POLICIES

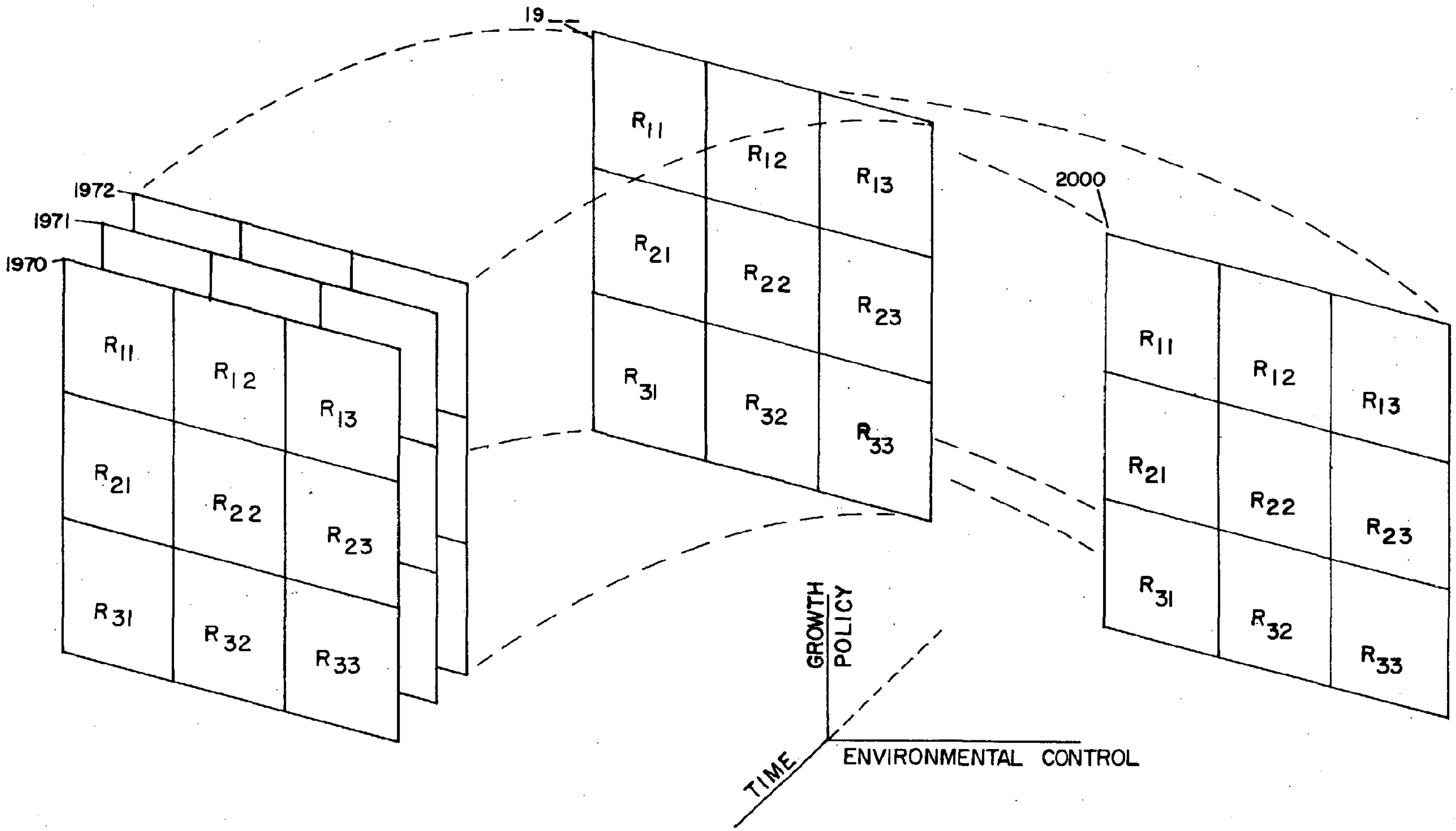
TABLE III. 2A

		COOLING POLICY		
		C_1	C_2	C_3
GROWTH POLICY	G_1	R_{11}	R_{12}	R_{13}
	G_2	R_{21}	R_{22}	R_{23}
	G_3	R_{31}	R_{32}	R_{33}

NINE ALTERNATIVE FUTURES AS OBTAINED FROM THREE GROWTH POLICIES AND THREE COOLING POLICIES

FIGURE III.3A

COASTAL ZONE
INFORMATION CENTER



ARRANGEMENT OF ALTERNATIVE FUTURE MATRICES OVER TIME

FIGURE III. 3B

are combined with the growth projections to develop the "alternative futures" that will be used throughout this analysis.

III.3 ALTERNATIVE FUTURES

The three growth projections developed in III.1 can be combined with the three environmental control policies developed in III.2 to create nine "alternative futures". Figure III.3A shows a 3 x 3 matrix in which this combination of three environmental control policies and three growth policies creates nine alternative possibilities at any point in time.

Figure III.3B illustrates the nature of this relationship over a period of time; a series of 3 x 3 matrices like the one appearing in Figure III.3A are arranged over time. If one were constructed for each year of the period being considered, 1970-2000 inclusive, there would be 31 such matrices arranged in a sequential manner.

CHAPTER IV

TECHNICAL CONSIDERATIONS IN THE PRODUCTION AND MOVEMENT OF ELECTRIC POWER

The electric power industry is one of the most complex, if not the most complex, single-purpose industry serving our society. The production and delivery of electric power requires exacting input from many disciplines, including thermodynamics, materials science, systems analysis, economics and fiscal management--to name only a few. Further complicating the situation is the nature of the real-time operation of the electirc power industry: when service is wanted, it is wanted instantly, and any failure to deliver, regardless of how quickly it may be overcome, is readily noticeable.

An understanding of some of the technical concepts involved in the electric power industry is crucial to following the procedure developed in this report. Chapter IV briefly details some of these technical concepts. Areas of principal concern include the need for a heat sink (i.e., thermodynamic requirements), costs for various cooling options, fuels, transmission considerations, etc. It must be kept in mind that this discussion only begins to touch the surface in a few technical areas of the power industry, and limits itself to those aspects that have a direct bearing on the overall objective of this project, namely to assess the environmental-economic trade-offs associated with waste heat disposal

IV.1 THERMODYNAMIC REQUIREMENTS FOR POWER GENERATION

More than 85 percent of the electricity currently consumed in the U.S. is produced using some form of a steam cycle. (National Power Survey, 1970) In Texas this figure exceeds 99 percent. (Governor's Advisory Committee on Power Plant Siting, 1972) The remaining fraction is hydro-electric power.

Some primary energy source is required to produce the necessary heat for the steam cycle. This source may be coal, natural gas, fuel oil, or nuclear fission.

The heat source makes no significant difference as far as the cooling aspects are concerned. The comments, observations, and data presented in this report are generally applicable to both fossil-fuel and nuclear-powered facilities. Any differences will be noted and discussed. For a given electrical output a nuclear facility does reject more waste heat than a modern fossil fueled plant of the same size. This lower efficiency is caused by operating the nuclear facility at lower temperatures and pressures to meet safety requirements.

A simplified schematic of the four principal components in a steam electric power generation plant is presented in Figure IV.1A. The functions of the boiler, the turbine, the generator and the condenser are briefly described:

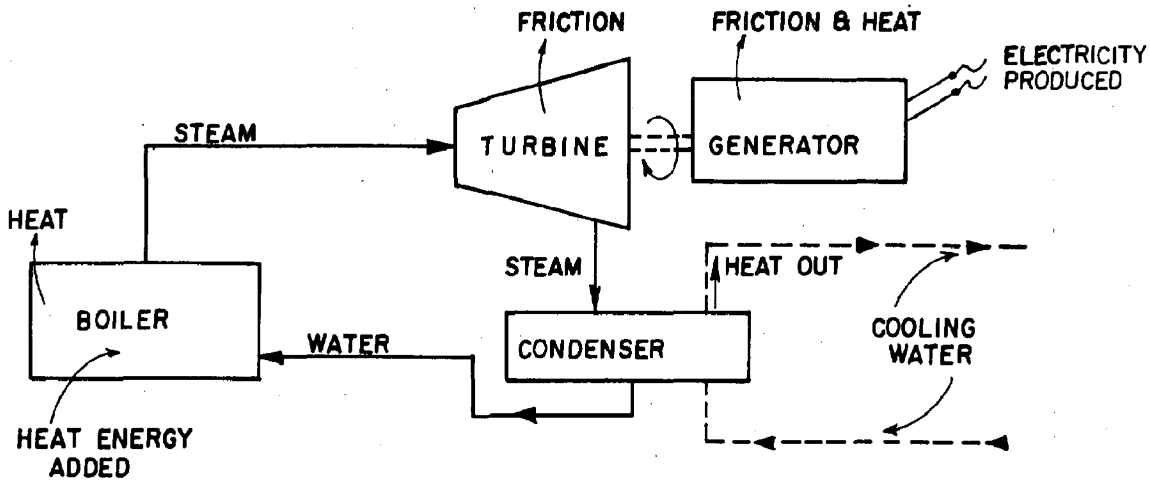
(1) The boiler takes the heat energy from the fuel and uses it to create steam from the water in the boiler. The function is the same for both fossil and nuclear plants.

(2) The turbine converts some of the heat energy contained in the steam to rotary mechanical energy; the rest is discharged outside the system.

(3) The generator converts the mechanical energy from the turbine into electrical energy for distribution and use.

(4) The condenser transfers the residual heat from the steam to the cooling water.

There are certain requirements and/or constraints that each of these highly complicated and intricate processes impose on the overall system which have direct implications on cooling requirements. Since this study deals in depth with cooling processes and their implications, principal characteristics of the



SCHEMATIC

UNIT	PRINCIPAL FUNCTION
BOILER	USE HEAT ENERGY TO RAISE THE INTERNAL MOLECULAR ENERGY OF THE STEAM.
TURBINE	CONVERT THE INTERNAL STEAM ENERGY, AS LINEAR MOLECULAR MOTION INTO ROTARY MECHANICAL ENERGY.
GENERATOR	USE THE ROTARY MECHANICAL ENERGY TO GENERATE ELECTRICAL CURRENT
CONDENSER	CONDENSE STEAM AND PROVIDE A VACUUM EXHAST PRESSURE ON TURBINE.

ENERGY TRANSFORMATIONS

PRINCIPAL COMPONENTS IN STEAM ELECTRIC
POWER GENERATION PLANT
FIGURE 1V. I A

thermo-electric process that affect cooling are discussed.

The best obtainable overall efficiencies of modern power generation plants are about 30 percent and 40 percent for nuclear and fossil-fueled plants respectively. However, relatively few people understand why these seemingly low efficiencies are currently the best obtainable, considering our modern technology, or why the prospects for significant improvements are not more encouraging. In order to explain this present situation and to justify projections of continued high heat rejection rates, some basic thermodynamic concepts must be examined and their implications for power production explored.

Principal Characteristics of the Thermo-Electrical Process

Thermodynamics is one of the most complex sciences challenging engineers and scientists. It is continually encountered in all ventures, ranging from water pollution control, to human physiology, to nuclear sciences, to materials science, etc. Of the three basic laws of thermodynamics, the Second Law of Thermodynamics (Thermodynamics, Faires, 1962) governs the maximum efficiency of power plants. The Second Law is defined by the following general expression:

$$dS = \frac{d\,Q_{rev}}{T} \qquad \text{(Eq. IV.1.1)}$$

where

S = entropy (BTU/R)

Q_{rev} = heat added in a reversible process (BTU)

T = absolute temperature (°R)

The change in entropy can be defined as:

$$\int_1^2 dS = S_2 - S_1 = \int_1^2 \frac{d\,Q_{rev}}{T} \qquad \text{(Eq. IV.1.2)}$$

For the purposes of illustrating the constraints imposed on the thermal power generation process, the relationship can be reduced to:

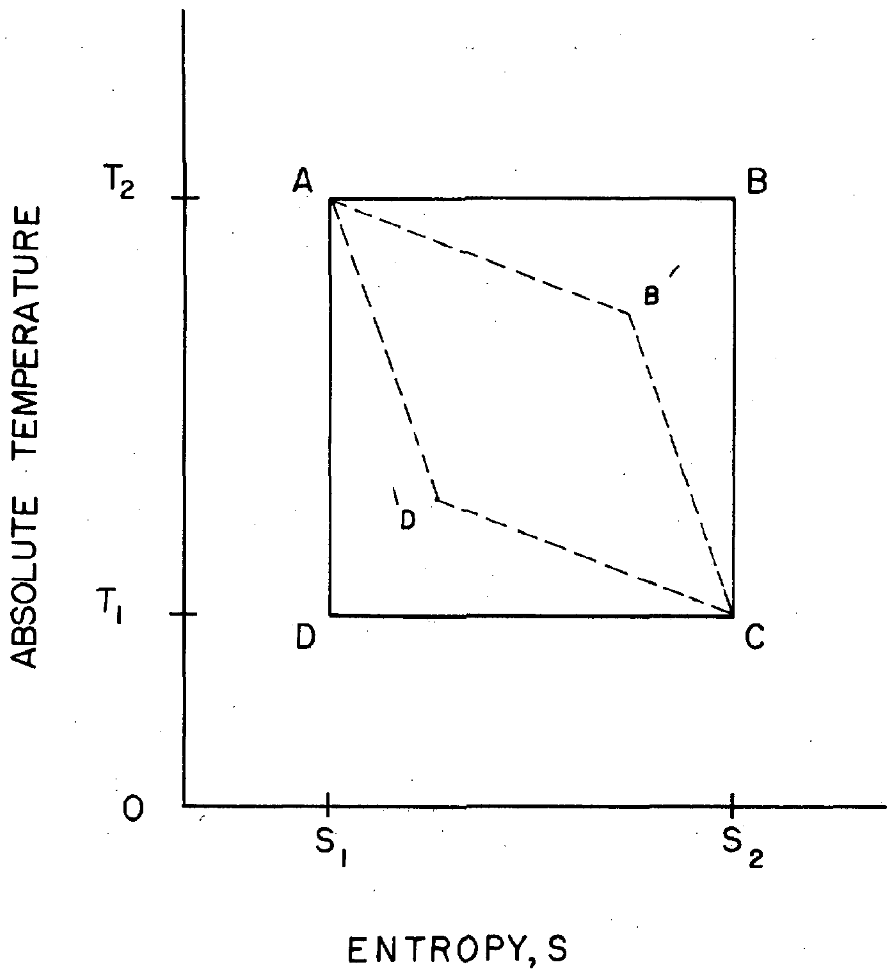
$$S = \frac{Q}{T} \quad \text{or} \qquad \text{(Eq. IV.1.3)}$$

$$Q = TS \qquad \text{(Eq. IV.1.4)}$$

Thermal energy of a substance is defined as the molecular energy of that substance. For gases this energy is mostly kinetic and for liquids and solids, mostly potential. If such a substance is heated, thermal energy increases, and the temperature also increases. The addition and removal of heat to or from a substance amounts to adding and subtracting energy from that substance. This process is just as much adding--reclaiming work as raising a weight and letting it come back down. (Löf and Cootner, 1965)

A plot of T vs. S for an ideal heat engine is shown in Figure IV.1B. For this ideal engine it is necessary to assume that the engine is self-contained and operates continuously, which in turn means that the engine is working through a closed cycle, i.e., the ending state is identical to the initial state.

The areas under the curves in Figure IV.1B represent heat inputs to or outputs from the system. Thus, since heat is a form of energy, if we can find the total heat added to the system and the total heat removed from the system, the amount of heat energy converted to another form of energy and "used" to do work by the heat engine can be calculated. Therefore the work done by such an engine is defined by the area contained within the polygon described by the T-S cycle. This means that the most efficient such cycle takes the form of a rectangle because the maximum area exists between the maximum temperature (T_2) line and the zero temperature axis, i.e., rectangle ABS_2S_1. Also the area bounded by ABCD is obviously greater than the area bounded by AB'CD. The rectangle will always contain the largest area for the given maximum and minimum values of S and T. Thus, in order to



T-S DIAGRAM: TEMPERATURE-ENTROPY RELATIONSHIPS FOR AN IDEAL HEAT ENGINE (AFTER COOTNER & LOF)

FIGURE IV. IB

maximize the work output of an ideal heat engine, it is necessary to maximize the area within the T-S diagram.

The implications of this basic premise of the Second Law of Thermodynamics on the overall cooling efficiency are substantial. One must strive to maximize the temperature at which heat is added (AB), and then provide as low a temperature as possible for the waste heat to leave the system (CD). The other two steps (BC, DA) are constant entropy processes with temperature changes. In the ideal engine the cycle is called the Carnot cycle, and all of these actions must be done in a frictionless, reversible manner. A real engine, using steam as the working fluid, cannot reproduce this cycle for numerous reasons, both theoretical and practical.

The Carnot cycle begins at point D, ($T_1 S_1$); the working fluid is compressed which raises its pressure and temperature, without adding any heat; the entropy is held constant at S_1 for this step, which moves to point A (T_2, S_1). On the next step, going from A ($T_2 S_1$) to B ($T_2 S_2$), heat is added, but the temperature is kept constant by permitting the fluid to expand. At this step the fluid, while it is expanding, is also doing work, such as driving a piston. At point B ($T_2 S_2$), the heat source is "shut off", but the gas is allowed to continue its expansion; for an ideal fluid, the total heat content stays constant (S_2) but the continued expansion results in a loss in both temperature and pressure, a loss which continues until point C ($T_1 S_2$) is reached. At point C ($T_1 S_2$) it is necessary to compress the working fluid; however, if this compression is to be a constant temperature process as indicated along (CD) it is necessary to release heat ($S_2 - S_1$) to the surroundings. This continues until point D ($T_1 S_1$) is reached where the cycle begins again.

Since steam is not an ideal fluid, these same exact relationships do not apply to a real thermo-electric plant. The concepts, however, are the same, and the ideal situation serves to illustrate why major improvements are not possible with current steam-electric generation methods even with the most advanced technology.

The following relationships are apparent:

Energy Input (Total Heat Input) = Area (ABS_2S_1)

Energy Converted to Work = Area (ABCD)

Energy Discarded (Waste Heat) = Area (DCS_2S_1)

$$\text{Efficiency} = \frac{\text{Work}}{\text{Input}} = \frac{ABCD}{ABS_2S_1} \qquad \text{(Eq. IV.1.5)}$$

For the theoretical efficiency to reach 100 percent, the energy discarded will have to be zero, but for this to happen the area of the rectangle DCS_2S_1 must be zero. The only way for this phenomenon to occur would be to have a T_1 equal to absolute zero (-460°R) which is not possible. About the lowest year round temperature sink in the U.S. is on the order of 60°F. For the South Texas study area substantially higher temperatures are common for much of the year.

Calculation of the maximum theoretical efficiency can readily be done using Figure IV.1B and the definition of efficiency already given:

$$\text{Efficiency} = \frac{ABCD}{ABS_2S_1} \qquad \text{(Eq. IV.1.5)}$$

where

$$ABCD = (T_2 - T_2) \cdot (S_2 - S_1)$$

$$ABS_2S_1 = (T_2 - 0) \cdot (S_2 - S_1)$$

$$\text{Efficiency} = \frac{(T_2 - T_1)\ (S_2 - S_1)}{T_2\ (S_2 - S_1)} = \frac{T_2 - T_1}{T_2} \qquad \text{(Eq. IV.1.6)}$$

or, converting to percentages and adjusting terms:

$$\text{Efficiency} = (1 - \frac{T_1}{T_2})\ 100 \qquad \text{(Eq. IV.1.7)}$$

Thus, it becomes obvious that the only way for the efficiency to become 100 percent is for the T_1/T_2 ratio to become zero. But this implies that T_1 would have to be an absolute zero which, of course, is unrealistic.

Practical Bounds on Plant Efficiencies Using Ideal Thermodynamic Cycle

The maximum combustion temperatures attainable with fossil fuels are about 2500°F (approximately 3000°R), but the actual operating temperature of modern fossil-fueled plants is closer to 1200°F (1660°R). This lower value is used in operational plants because it is the maximum temperature that current materials can operate under for prolonged periods without possible adverse effects. The turbulence and randomness which exist in large furnaces also tend to hold the actual temperature well below the theoretical maximum. For a sink temperature of 60°F and an operating temperature of 1200°F, the theoretical efficiency is given by:

$$Eff^t = (1 - \frac{520}{1660}) \times 10^2 = 68 \text{ percent}$$

Modern fossil-fueled plants are achieving about 60 percent of the theoretical Carnot cycle efficiency, thus providing an actual maximum thermodynamic efficiency of about 40 percent.

Nuclear plants also depend on the steam cycle, and also are constrained by the same thermodynamic principles. However, nuclear units must operate at even lower temperatures because of special safety factors and material limitations of the reactor fuel rods. Typical maximum temperatures are on the order of 650°F (1110°R) which results in a theoretical efficiency of 55 percent and an operating efficiency (assuming 60 percent of ideal efficiency) of about 32 percent. Thus, for every BTU of energy which goes out over the wires as electricity from a nuclear facility, approximately two BTU's of energy must be dissipated into the environment as waste heat.

It is not likely that greatly increased initial temperatures will be possible. In fact, lower average temperatures are likely to be the rule as an increasing portion of all power is produced by nuclear reactors. Efficiency methods to lower the exhaust temperature, improve the mechanical efficiency of turbines, or decrease losses in the generator must be developed if the overall process efficiency is to be increased.

Lowering the exhaust temperature is an attractive alternative, but unfortunately man has little control over this variable, since the designer must work with the naturally occurring air and water temperatures.

Efforts to reduce exhaust temperatures have caused power-plant designers to turn to water as the principal cooling source. The simplest way to get rid of the steam after use in the turbine is simply to exhaust it into the atmosphere. However, through the use of a cooling fluid, a partial vacuum can be created beyond the turbine, and the efficiency can be significantly increased. Therefore water cooling is currently used in all U.S. thermal power plants. The steam is condensed into liquid and circulated back to the boiler for use as re-cycled boiler feed water.

In the proposed dry cooling towers, water would still be used to remove the heat from the back of the turbine. However, instead of releasing this heated water directly into the environment, or passing it through wet towers to be cooled by evaporation, the water would go through heat exchange where the cooling medium would be at the atmosphere. After cooling, the water would be sent back to the turbines to act as a heat sink for the exhaust steam again.

Other unique cooling possibilities may exist at specific sites, such as a deep reservoir nearby where cold water could be drawn from near the bottom, or possible offshore sites in deep water. However, in all cases, the plant designer is limited to natural conditions.

Unlike the thermodynamic problem, there is no theoretical principle that limits turbine efficiency. However, some major practical problems/ constraints exist.

The objective of a turbine is to convert the internal molecular energy which will ultimately be used to drive a generator. The steam is allowed to expand in one direction along the turbine axis. The steam expands and moves many series of intricate blades which cause the shaft to rotate. The design objective is to transform a maximum amount of the steam's internal molecular energy into rotary motion of the turbine.

Turbine losses principally result from friction, turbulence, and leakage. As the steam molecules encounter the blades and cause them to rotate, a certain amount of friction is produced between the molecules and the blades. Also, there is some random turbulence within the steam going through the turbine; this non-linear motion does not contribute to the turbine's operation. Another significant energy loss results from leakage of the steam around the turbine's blades. Even though design and fabrication is very precise, some leakage is inevitable. The full-load efficiency of the best turbines approaches 85 percent. However, this efficiency can drop off rapidly if such turbines are not operated at their design loads, or if minor imperfections are allowed during fabrication and installation.

The current limiting constraint for nuclear plants is the 650°F maximum sustainable temperature for the fuel cells and control rods. The basic principle for combustion in a fossil-fueled plant simply is to add air and fuel to a furnace at the necessary temperature, provide agitation to bring the two into contact and let the fuel and oxygen burn. This process is not 100 percent efficient. The principal losses result from incomplete combustion, heat loss with exhaust gases, and inefficiencies in the heat transfer process from the combustion gases to the working fluid. While relatively little progress has been made in improving the thermal efficiency of boilers beyond about 90 percent, considerable improvements in the economic efficiency (i.e., fuel savings) of such operations have been achieved.

The generation process involves conversion of the rotary motion of the turbine shaft into electrical energy. The currently best possible mechanical-electrical conversion efficiencies exceed 95 percent, but no significant increase above that is anticipated. Principal problems usually result from material failures or fabrication shortcomings which cause overheating. Some utility personnel feel that the generator probably is the most efficient, trouble-free component in the entire generation system. (Personal Communication, 1972)

Summary of Current Capabilities and Prospective Improvements in Efficiency of the Generation System

(1) Theoretical constraints imposed by the Second Law of Thermodynamics, and naturally occurring air and water temperatures limit the theoretical efficiencies of fossil-fueled plants to 68 percent, and nuclear plants to 55 percent.

(2) Practical design and operating considerations lower their best attainable efficiencies to approximately 40 percent and 32 percent respectively.

(3) Nothing on the drawing board or in the conceptual stages promises to provide a significant substitute for steam-cycle plants.

(4) No method of greatly increasing these efficiencies appears likely in the foreseeable future.

(5) Taken collectively, advances in generation technology will not have a significant impact on the overall production of waste heat requiring disposal.

IV.2 COOLING ALTERNATIVES

There are several compelling facts that emphasize the need for new cooling technology. The demand for electricity will continue to grow; present and new generation facilities will continue to rely on some form of the steam-electric cycle; plant efficiencies will not greatly increase above the current levels; energy will become relatively scarcer with increasing demands; competition will drive prices up; curtailments and mandatory allocation will be a reality; and the environmental regulations on waste heat disposal will continue. Therefore, new cooling technology must be developed and applied to meet these environmental constraints under increased loads, at the lowest possible cost, and with the minimum expenditure of additional energy. This section details the alternatives available for handling this future waste-heat load and discusses the merits and liabilities of each cooling system.

Considerations in Choosing Cooling Systems

When making decisions between two or more alternatives, factors other than the capital and operating costs of the equipment must be considered. Some of the related considerations include:

(1) Flexibility - How well can a given cooling system be modified to meet changing standards? As more and more agencies get into the regulatory business, it becomes necessary for the utility to anticipate future requirements. The advantages of a system which can be readily upgraded become apparent.

(2) Resource Requirements - A given system may "solve" the thermal discharge problem, but may create associated difficulties or require increased amounts of other resources which make the system impractical. For example, fresh water cooling towers on a closed-cycle system would eliminate thermal discharge into an estuary, but the consumptive use of water in such towers might

require withdrawal of essentially all of the fresh water inflow to the estuary. Such reduction of inflows would be more detrimental than the addition of thermal energy--a classic case of the cure being worse than the illness. Land requirements for cooling ponds, or energy requirements for dry tower operations, are examples of other resource requirements which must be considered and assessed.

(3) Public Image - Most private and public electric utilities have fallen under criticism from environmental groups and consumer advocates. If a cooling system can be selected, designed and operated in a manner to produce and show associated benefits to society, then it becomes a valuable public-relations asset. Some examples would be a cooling pond used as a fishing reservoir; a viable aquaculture project; possible open-space and recreational areas near a plant, etc.

(4) Adaptability to Intermittent Operation - The likelihood of fuel shortages for fossil-fueled plants is a certainty. This situation makes it desirable to have a cooling system which can operate on a "go-stop-go" basis with a minimum of special attention.

(5) Flexibility in Cost Trade-Offs - Situations are certain to develop where it may be desirable to deviate from a strict minimization of the total amortized capital cost plus operating expenses. The high cost of money, $8\frac{1}{2}$ to 9 percent, coupled with other uncertainties, may make it more attractive to save on the initial investment and endure higher operating costs.

The individual decisions to be made in selecting a specific cooling technique for a given plant will depend upon all of the above, plus other less tangible factors such as the attitude of the utility's management, the local regulatory "climate", recent experiences with regulatory authorities, local public attitudes, etc. While all of these considerations are significant and may ultimately be more important than strictly technical-economic considerations, detailed development and exploration of such non-quantifiable concerns will not be attempted in this report.

Heat Dissipation

Outer space is the ultimate sink for all waste heat from the generation process. Heat rejection systems capable of direct atmospheric heat disposal are conceptually possible but because of practical considerations, water is used to remove the heat from the condenser in all existing U.S. thermal-electric power plants. The water either gives off the acquired heat energy directly to the atmosphere or transfers the heat to larger water bodies where the energy is eventually given off to the atmosphere.

These processes of evaporation, radiation, conduction, and convection are the same for once-through, cooling ponds, spray ponds, or wet towers. Different systems simply alter the relative importance of the individual processes. For example, radiation may predominate in ponds where evaporation accounts for the bulk of energy transfer in wet towers.

The classical depiction of the air-water interface (Edinger and Geyer, 1965) is presented in Figure IV.2A. The general energy budget for a unit surface area of a reservoir can be written as follows (Krenkel and Parker, 1968):

$$Q = (Q_s - Q_r) + (Q_a - Q_{ar} - Q_{bs}) + Q_v - Q_e - Q_h - Q_w \qquad \text{(Eq. IV.2.1)}$$

where (all Q's given in BTU/FT^{2}Day):

Q = increases in energy stored in the body of water

Q_s = short-wave radiation incident to the surface

Q_r = reflected short-wave radiation

Q_a = incoming long-wave radiation from the atmosphere

Q_{ar} = reflected long-wave radiation

Q_{bs} = long-wave radiation emitted by the body of water

Q_v = net energy brought into the body of water by inflows, including precipitation

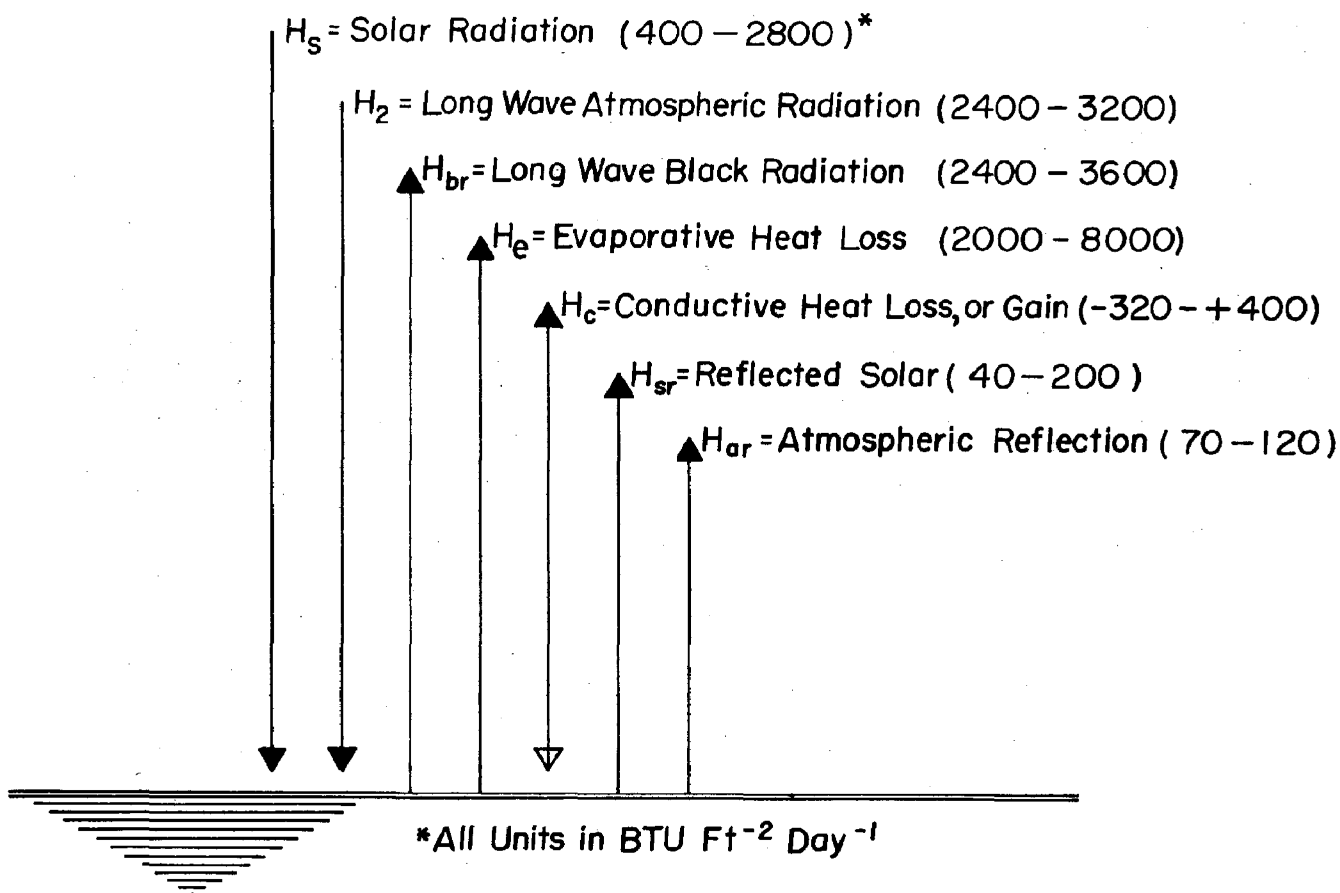
Q_e = energy utilized by evaporation

Q_h = energy conducted from the body of water as sensible heat

Q_w = energy carried away by the evaporated water

Four terms in equation IV.2.1 are of particular interest because they describe the mechanisms by which all waste-heat energy must be dissipated from a power plant. These terms are evaporation ($Q_e + Q_w$), conduction (Q_h), and radiation (Q_{bs}). Figure IV.2A shows the major terms in the liquid-air heat transfer equation and indicates their relative importances.

Analysis of the detailed behaviour of thermal discharges generally involves the mathematical modeling of the hydrodynamic characteristics of the outfall. This process is coupled with a model which describes the dissipation of the thermal energy simultaneously into both the surrounding water mass and the atmosphere. The ecological impact of the heated effluent also must be assessed. Techniques generally are established and well accepted to perform the first two analytical steps. Unfortunately, no such methods currently exist for determining the ecological impact of such discharges. In fact, considerable disagreement exists over whether such discharges are significantly detrimental, especially in climates where the aquatic ecology is essentially composed of warm-water species. In-depth discussion of such analytical techniques is beyond the scope of this report.



HEAT TRANSFER ACROSS THE AIR-WATER INTERFACE
(AFTER EDINGER AND GEYER)

FIGURE IV.2A

Processes for Disposing of Waste Heat

Once-through cooling is the most elementary method of disposing of waste heat. Three basic devices--ponds, wet towers, and dry towers--may also be used to supplement once-through cooling in a non-recycling system, or to replace the once-through system with some sort of closed system. Taken in combination, and considering both fresh and salt water, a number of possibilities shown in Table IV.2A can be developed. These data indicate that the availability of fresh or salt water for cooling is a most important consideration.

Careful differentiation is necessary between the cooling devices and the system arrangement. "Device" refers to the mechanical/physical apparatus used, and may be a pond, tower, etc. "System" arrangement means the way the device is used. For example, a pond or tower can either be used in a closed system (i.e., one employing recycling), or as supplemental cooling in a once-through arrangement. A closed-cycle system is compared to a once-through system with supplemental cooling in Figure IV.2B.

Most devices may be used in either a closed cycle or a supplemental system. Technology is not presently available, however, to build salt-water cooling towers. Corrosion is a minor problem, but the principal difficulty results from salt mist drift from such towers which can cause devegetation and other difficulties. If salt water is to be used in closed-cycle pond systems, a considerable amount of the recirculating water must be discharged and replaced to prevent the build-up of solids in the system. Excessive solids will cause scaling, mineral deposits, and impair the efficiency of the heat exchanges.

Factors other than environmental protection or cost may combine to determine whether or not once-through, closed-cycle, supplemental, or dry systems are to be used. The principal design parameters which must be considered for cooling devices are summarized in Table IV.2B. For example, in

SYSTEM/DEVICE	FRESH WATER	SALT/BRACKISH WATER
ONCE THROUGH	Y	Y
CLOSED CYCLE		
REGULAR PONDS	Y	L
SPRAY PONDS	Y	L
WET TOWERS	Y	N
SUPPLEMENTAL		
REGULAR PONDS	Y	Y
SPRAY PONDS	Y	L
WET TOWERS	Y	N
DRY TOWERS	Y(na)	Y(na)

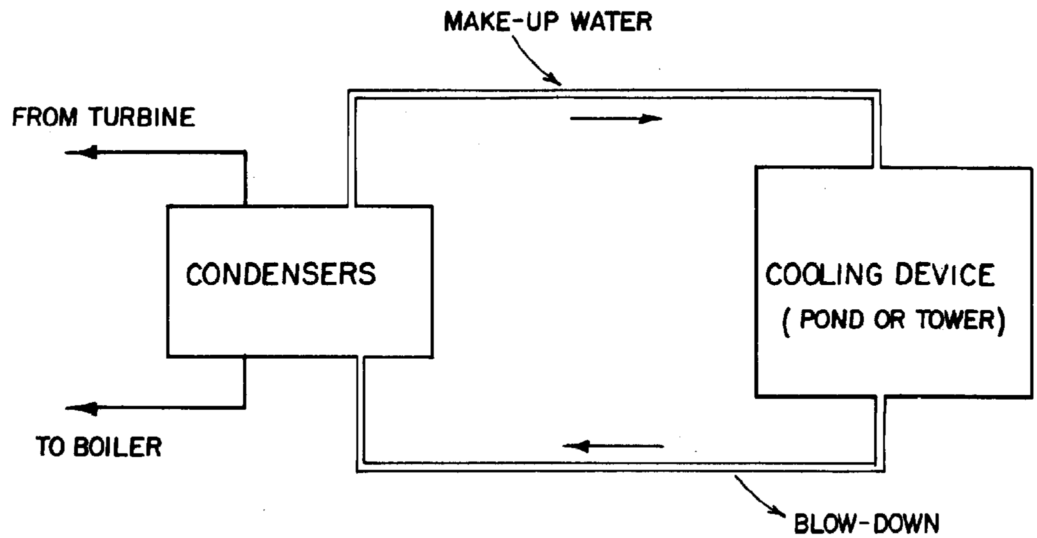
Y = YES, CURRENTLY READILY AVAILABLE AND USABLE

L = GENERALLY USABLE, BUT CERTAIN FACTORS MAY SIGNIFICANTLY LIMIT THEIR USE.

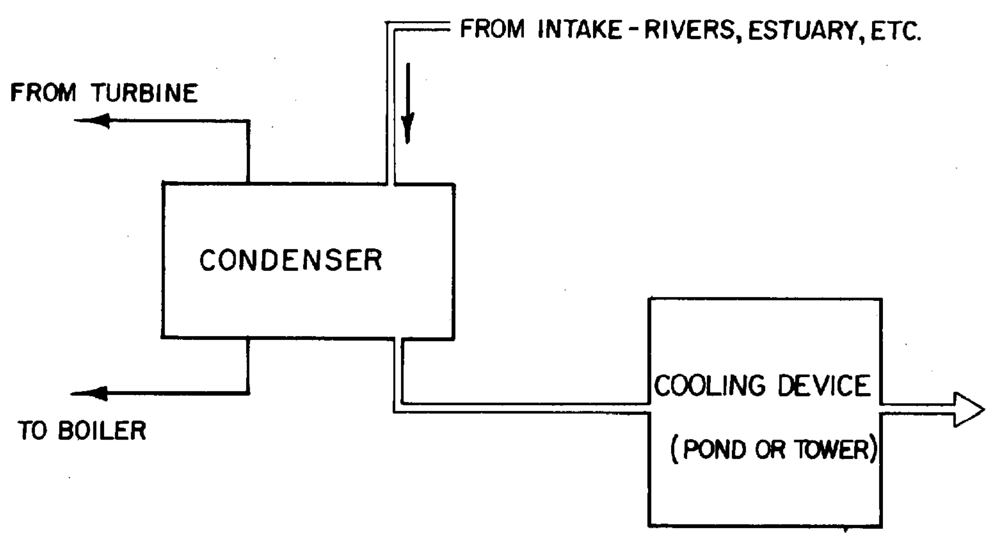
N = NOT CURRENTLY AVAILABLE DUE TO TECHNOLOGICAL CONSTRAINTS

na = NOT APPLICABLE – ie, IN THE CASE OF DRY TOWERS, COOLING WATER IS NOT NEEDED.

PRINCIPAL COOLING TECHNIQUES
TABLE IV.2A



CLOSED CYCLE COOLING



SUPPLEMENTAL COOLING

CLOSED CYCLE AND ONCE THROUGH
COOLING SYSTEMS
FIGURE IV.2B

DESIGN PARAMETERS	WET BULB TEMP.	DRY BULB TEMP.	BAROMETRIC PRESS.	WIND VELOCITY	CLOUD COVER	LATITUDE	SOLAR RADIATION	STEAM-FLOW (MAKE-UP)
ONCE THROUGH	1	1	2	1	1	2	1	1
REGULAR POND	1	1	2	1	1	2	1	2
SPRAY POND	1	1	2	1	2	2	2	2
WET TOWER(ND)	1	1	2	0	0	0	0	2
WET TOWER(MD)	1	2	2	0	0	0	0	2
DRY TOWER	2	1	2	0	0	0	0	0

1 = Prime importance

2 = Secondary importance

0 = Minimal importance

PRINCIPAL DESIGN PARAMETERS FOR VARIOUS COOLING DEVICES

(AFTER CHENEY & SMITH, 1969)

TABLE IV. 2B

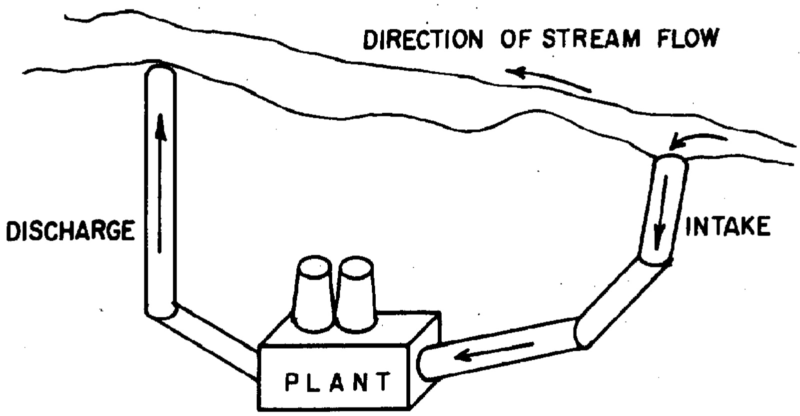
some water short areas plagued with intermittent or fluctuating stream flows, closed systems containing substantial on-line storage may be used to insure the availability of cooling water. Similarly, in arid coastal regions, any fresh-water cooling may be avoided because of competing uses for the same limited fresh-water supplies.

Once-Through Cooling: Advantages and Disadvantages

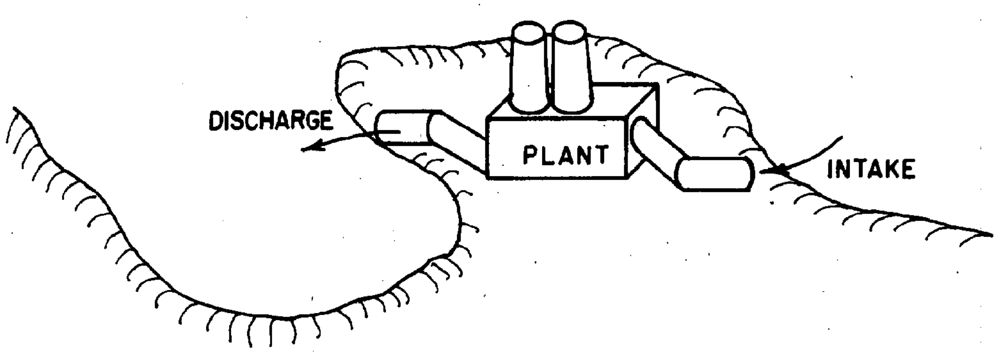
This method is generally used whenever possible because of simplicity and low cost. Typical once-through configurations for the river and coastal situations are shown in Figure IV.2C. Environmental constraints on thermal discharge, however, often prohibit this process. This method also requires substantial amounts of water. Approximately 30-50 gallons/KWH are circulated through the condensers, but the consumptive use is only about 0.20-0.30 gallons/KWH. This consumptive use is about the same as for cooling ponds. Once-through cooling is equally applicable to either fresh or salt water; however, the costs of a system for salt water normally are slightly higher.

Cooling Ponds: Advantages and Disadvantages

Ponds often are used when substantial land area is available at a moderate cost. Two typical cooling-pond configurations are illustrated in Figure IV.2D. The surface area for a given size plant depends on local meteorological conditions. One study (Vanderbilt, 1971) examined the effect of geographical location on cooling-pond performance and design. The literature is filled with detailed studies of the mechanics of evaporation dating back to the Lake Hefner Project (Anderson, 1954) and with detailed evaluation and design procedures for sizing cooling-ponds (Raphael, 1961; Edinger and Geyer, 1965; Dynatech, 1971).



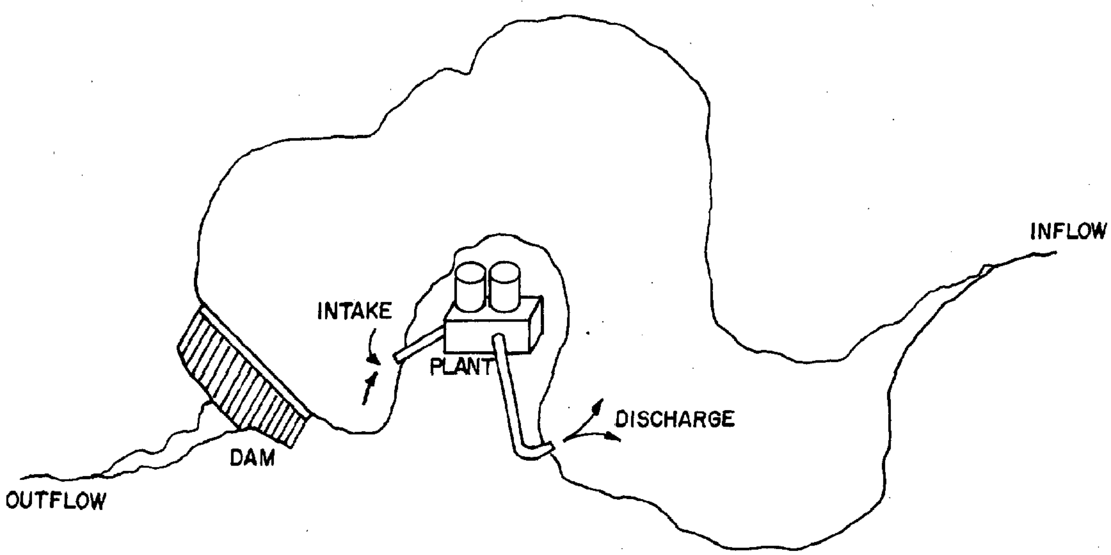
RIVER



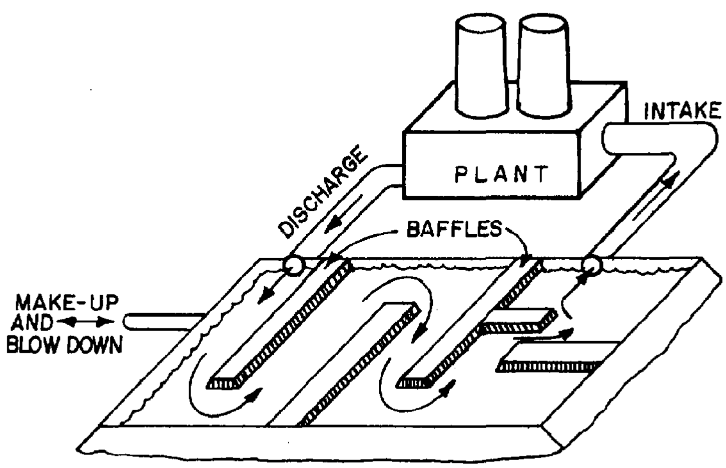
COASTAL

TYPICAL ONCE THROUGH COOLING CONFIGURATIONS

FIGURE IV. 2C



RESERVOIR BEING USED AS A
COOLING POND



DIKED, OFF CHANNEL POND

TYPICAL COOLING POND CONFIGURATIONS
FIGURE IV. 2D

The many variables involved in estimating pond size plus the wide fluctuations naturally inherent in these variables due to location and meteorological phenomena, generally cause most regulatory bodies to insist on large safety margins (i.e., "over-designs") to minimize the likelihood of undesirable environmental impact. The pond performance is most crucial during the summer season when the natural conditions are least favorable. Most utilities in Texas use a rule-of-thumb method for sizing ponds. (Personal Communications, 1972, 1973) For a modern fossil-fueled plant the norm is approximately 1.0 acre/MW (megawatts) and for nuclear plants this increases to 1.5 acre/MW. Data presented in the Vanderbilt study (1971) indicate that the natural conditions that may occur across Texas during summer months tends to substantiate this rule-of-thumb procedure. Another rule-of-thumb method (Dynatech, 1969) also is approximately the same; namely 1 acre/MW + 20 percent for fossil-fueled plants and 2 acre/MW for nuclear plants.

Edinger and Geyer (1965) identify three principal types of cooling ponds: completely mixed, flow-through (plug-flow), or internally-circulating ponds. Flow-through ponds, where the temperature decreases linearly between the plant discharge and the plant intake or pond outfall, is the type most commonly found at power plants in Texas. The inlet and outlets are usually so located to insure this type of behavior. In simple rectangular ponds, baffles can be added to maximize travel distance and prevent short circuiting. In Figure IV.2D the lower example is typical of this design.

Unfortunately, ponds alone are not always capable of returning heated water to the original ambient temperature if the initial water and air temperatures were about the same. As one author (Dynatech, 1971) points out, a pond of infinite size would be required to cool the water back to equilibrium temperature. The same source observes that bout the best pond-cooling attainable under practical conditions still leaves a 2-3°F net temperature rise. If regulatory agencies required a temperature rise of less than 2°F, ponds used alone would not always be satisfactory under certain conditions.

In the study area, several types of cooling ponds are postulated, including a diked salt or brackish water pond with baffles; an off-channel, fresh-water pond, probably built in a shallow valley; a shallow reservoir, and a deep reservoir. The latter two would almost certainly be general, multi-purpose facilities providing water supply, flood control, and recreation, in addition to power plant cooling. The off-channel, fresh-water pond would probably not be multi-purpose in the general sense, although such a pond might be used for aqua-culture activities with the surrounding land developed as recreational open space.

Cooling pond costs are normally a direct function of land price. Simple ponds may be only slightly more expensive than once-through systems unless land is very costly. However, if a major reservoir is being used as a cooling pond, and a substantial portion of the reservoir cost is allocated to the electrical utility, then cost can become quite significant. In certain instances, it may be expedient for the utility to purchase existing water rights from other users (e.g., irrigation interests) and these costs could add a non-trivial expense.

Evaporative Towers: Advantages and Disadvantages

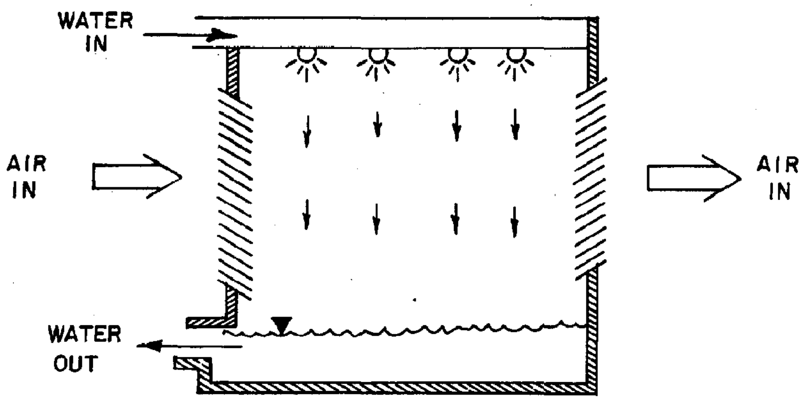
Wet cooling towers capitalize on the significant amount of energy required to evaporate water. The energy source for this physical process is the excess thermal energy, i.e., waste heat, contained in the cooling water. For a typical fossil-fueled facility, an evaporative loss of about 0.75 gallons/KWH may be experienced at a heat rejection rate of 5300 BTU/KWH. Evaporation accounts for about 75 percent of the cooling in wet towers compared to about 25 percent for once-through or ponds. These specific rates vary substantially with geographic location and transient meteorological conditions.

Evaporative cooling towers can be natural draft (ND) towers or mechanical draft (MD) towers. In the ND towers, several natural phenomena are allowed to work collectively to produce updrafts and the evaporative cooling effect. MD towers utilize blowers to supplement the natural processes.

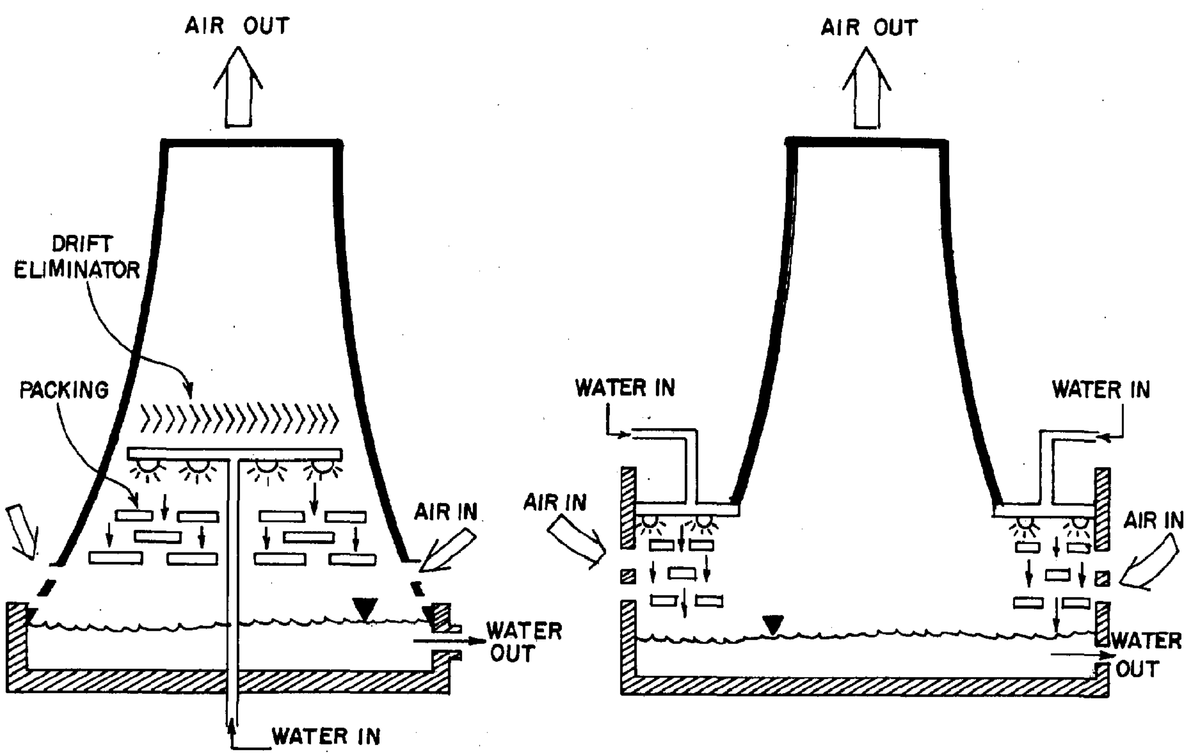
The principal design factors are the temperature and enthalpy differences between the water and the air. Other significant parameters include barometric pressure, wind velocity (especially for certain ND designs), water quality, and the nature of the air-water interface. The tower is designed to maximize the interfacial contact area between the air and water masses. Various design configurations within each of these two categories are possible.

Natural Draft Towers--ND towers are somewhat simpler than MD towers because they have no mechanical devices to enhance air flow. However, this same fact makes them more dependent on atmospheric conditions and necessitates larger structures. ND towers come in three basic configurations: spray-filled, counterflow, and crossflow (Dynatech, 1969). These are shown in Figure IV.2E.

The spray-filled, or atmospheric tower (Figure IV.2E.1), is the simplest possible design and can be built with or without internal packing. The water enters the top of the tower in small droplets and falls through the tower to the bottom where it is removed. These towers are built with a flat side perpendicular to prevailing winds to maximize air through-put. Closely-spaced louvres serve to minimize the drift losses on the downwide side while the same louvres induce some turbulence in the incoming air streams. Such towers are the least expensive to construct and provide relatively trouble-free maintenance, but are somewhat inefficient and provide a small cooling range. This low range, coupled with the sensitivity to changing winds, precludes the use of atmospheric spray towers on all but the smallest power stations.



IV.2E.1 SPRAY TOWER



IV.2E.2
COUNTER FLOW HYPERBOLIC TOWER

IV.2E.3
CROSS-FLOW HYPERBOLIC TOWER

TYPICAL NATURAL DRAFT EVAPORATIVE COOLING TOWERS (AFTER DYNATECH, 1969)
FIGURE IV.2E

All large ND towers currently in use are of the hyperbolic design. This particular design utilizes density differences between the air in the tower barrel and that outside to produce upward currents in the tower and thus create a natural draft. Air enters the tower at the base and is brought into contact with heated water. This heated, lighter air is displaced at the tower base by outside, cooler heavier air and the heated air is forced upward through the tower barrel. This phenomenon sets up a continuous process that usually produces verical exit velocities of 10-12 feet per second. Such velocities will drive the exit plume up and generally keep the moisture-laden air away from the ground and allow the heat to dissipate into the atmosphere without any adverse, localized ground effects.

Hyperbolic towers may be of counter-flow (Figure IV.2E.2) or crossflow (Figure IV.2E.3) design. The pressure differential concept is the basis for both; the way in which the air and water are brought into contact at the tower base is the main difference. Counterflow designs have slightly more cooling capacity for a given size because of superior air-water interfacial contact. However, there are about as many towers of each design currently being built. Typical designs are 300-400 feet tall with base diameters about 70 percent of height, and throat diameters about 50 percent of base diameters.

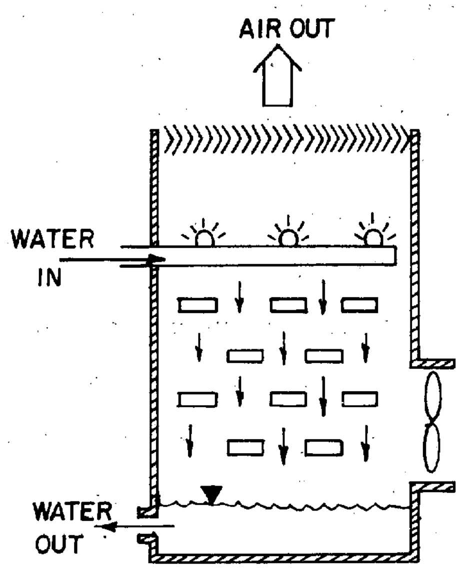
Hyperbolic towers usually are designed for the least favorable meteorological conditions; thus, over-designs are normal. However, all natural-draft towers perform well at off-design operating conditions.

Initial costs of hyperbolic, ND towers can be quite large, especially if the design includes the structural strength to survive 200 mph hurricane winds. However, the low operating costs, which include only a limited pumping head on the circulating water, and general facility maintenance, may compensate for higher capital costs.

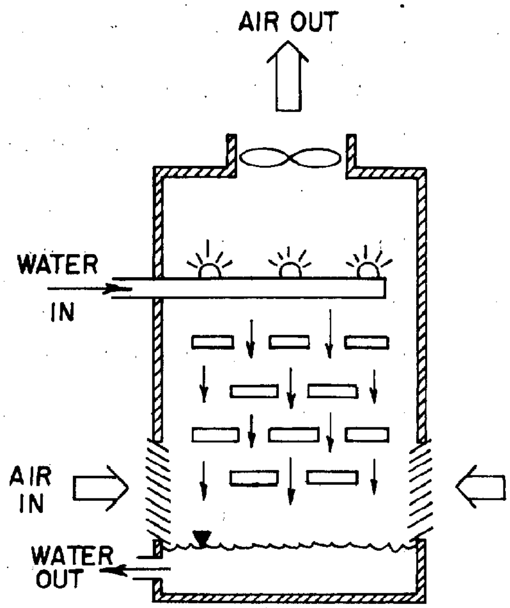
Mechanical-Draft Wet Towers--Mechanical-draft (MD) wet towers depend on the same physical mechanisms to transfer energy from the heated water to the atmosphere as do ND towers. The difference is that MD towers use blowers to move the large quantities of air through the towers to enhance contact with the water. These blowers eliminate the dependence on natural drafts and wind velocity, thus providing more control over the cooling process. MD towers also are significantly smaller than ND towers of equal heat transfer capacity. MD towers, in return, are more complex and require significant amounts of energy to run the blowers. Like ND towers, the design usually is based on the "worst" probable conditions. The blower through-put can be varied to conserve energy when operating at off-design conditions. Under certain conditions, moderately high winds can impede the performance of some MD towers. The three most common MD designs are the forced-draft, the induced-draft-counterflow tower, and the induced-draft-crossflow tower. These three configurations are shown in Figure IV.2F.

The simplest MD tower is the forced-draft design (Figure IV.2F.1). These towers are structurally easier and generally cheaper to build than other MD designs since the fan is located near the base. Also, placement of the blower at the inlet rather than at the outlet, greatly reduces erosion and corrosion on the fan blade and other mechanical parts. Stability difficulties restrict the maximum fan size to about 12 feet. In cold weather the blower mechanism may ice up, whereas in an induced system the blade is in the exhaust; and thus, freezing does not occur except in very extreme climates. Possible short-circuiting of exhaust air can cause significant difficulties. The forced-draft design is not widely used by the utility industry, although these systems have seen considerable application in the chemical and petrochemical industry.

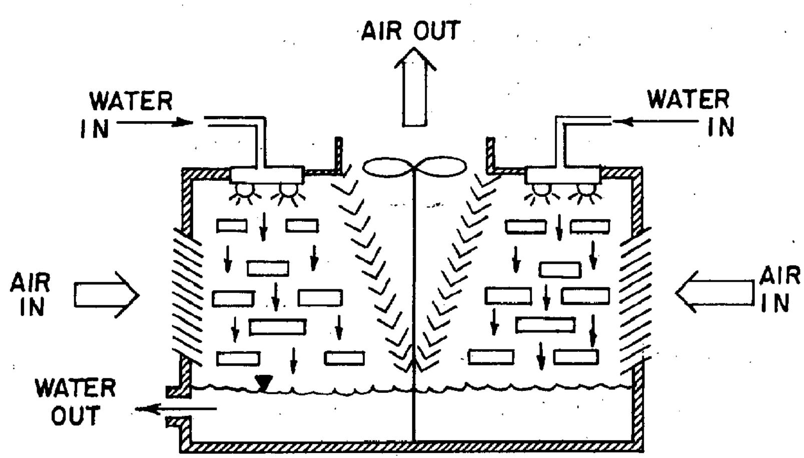
The induced-draft counterflow evaporative tower, shown in Figure IV.2F.2, is the most commonly used MD tower in the utility industry. These



IV. 2F. 1
FORCED DRAFT TOWER



IV. 2F. 2
INDUCED-DRAFT COUNTER FLOW TOWER



IV. 2F. 3
INDUCED-DRAFT CROSSFLOW TOWER

TYPICAL MECHANICAL DRAFT EVAPORATIVE COOLING TOWERS
FIGURE IV. 2F

towers typically are 60-75 feet high and have vertical exhaust velocities of 5-10 feet per second. The upward exit velocities are designed to push the exhaust stream upward with enough momentum to insure dissipation into the atmosphere, thus reducing possible ground fog and related undesirable effects. Counter-flow towers adhere to the general rule that any counter-flow heat exchanger device is more efficient than parallel-flow or cross-flow devices of equal size. By placing the blower in the exhaust stream, the threat of icing is greatly reduced, but the fan and supporting mechanical equipment is subjected to more erosive and corrosive elements. Even though the operating costs will increase, this is offset by the close control of the cooling process which is possible by blower output variation, allowing for relatively precise adjustment and selection of exhaust temperatures.

Induced-draft crossflow towers have many of the advantages of the induced-draft counterflow towers; however, crossflow towers are usually shorter and require less pumping head; this advantage often is offset by the requirement for substantially more blower horsepower. The crossflow design is generally less efficient at heat transfer than the counter flow configuration. It is more likely to ice up and require more land area than a counterflow tower of the same capacity.

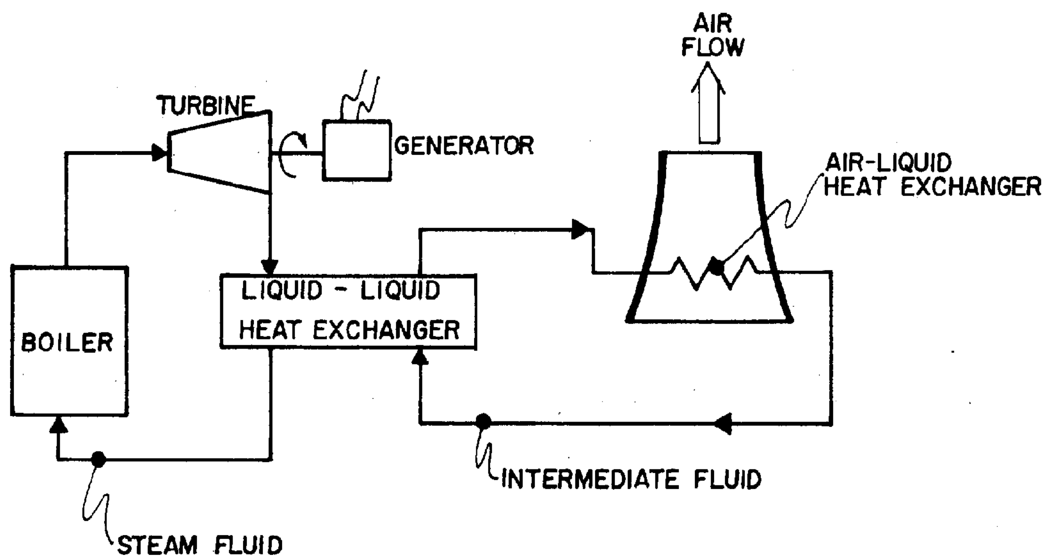
If evaporative cooling towers are to be used, and sufficient fresh water is available for their operation, the selection of the general type (ND or MD) and specific configuration depends on many considerations. Principal parameters include land area, anticipated energy (fuel) costs, corrosiveness of available water supplies, aesthetics, wind resistance requirements, etc. Actual selection of a type of system and subsequent design depend on many specifics which are beyond the scope of this investigation.

Dry Cooling Towers: Advantages and Disadvantages

If no water is available for cooling purposes, and if water quality regulations will not permit heated water discharges, dry-cooling towers offer a possible alternative. At this time, no dry towers are being used on power plants in the U.S. The only large dry towers currently in use are at Rugeley, England. There, a hyperbolic dry tower 350 feet in height and with base and throat diameters of 325 feet and 205 feet respectively, is being used to cool a 120 MW plant (Dynatech, 1969). Since the design is entirely a function of air temperature, a tower of similar size would have somewhat less cooling capacity in the hot Southwest where the temperatures are substantially higher than in England.

All large dry towers utilize the Heller cycle rather than direct air cooling of the steam-cycle fluid. Figure IV.2G shows a simplified schematic of the Heller system. The dry tower itself is essentially an air-cooled heat exchanger in which a cross-flow fin is located inside a chimney. The fin is designed to maximize the controlled air flow over the exchanger. Such towers can be either natural or mechanical draft. In this system, two loops of flowing water are used. One water system provides the usual working fluid for the steam cycle. The other water system receives the heat from this working fluid through a heat exchanger, and then goes to an air-cooled heat exchanger where its thermal energy is dissipated directly to the atmosphere.

The type of dry cycle which does not use an intermediate fluid is generally known as an air-cooled condenser. In this device, the discharge vapors from the turbine enter directly into the air exchanger and pass through finned tubes where air is blown over the tubes. The condensed liquid is returned to the boiler for another cycle. Such air-cooled condensers are used only for very small-cooling situations, and none have been developed



SIMPLIFIED HELLER SYSTEM

FIGURE IV. 2G

that would suffice for even a small power-generation plant.

While the know-how is readily available to design and build operational dry towers for even the largest power plants, several factors tend to limit their practical application. The capital cost of dry towers is more than double that of wet towers. Total operating cost, including amortization and fuel, may run four to five times that of wet towers. Of course, if no water is available, or if the water is very expensive, dry towers conceivably might be the logical economic choice. Sheer size creates another problem. A large modern plant of 3500 MW could require 20 or more towers 400 feet high and with base diameters of over 350 feet. The appearance of such a set of structures might be aesthetically unacceptable to the public, particularly in very flat terrain such as that along the Texas coast. In certain cases, competing land uses may eliminate dry towers because of the substantial land area required. Susceptibility to hurricane damage is another consideration. These structures which are usually large, thin concrete shells, would have to be designed to accommodate the 150 mph plus winds associated with the major hurricanes, and this would greatly increase costs. Restoration of electrical service after such a natural disaster is of utmost importance to all concerned; if a plant's dry towers were disabled, the plant could not operate--a situation that would not be encountered with other cooling processes.

Unlike other cooling systems, a dry tower cannot be viewed as an "add-on" cooling device, for dry towers must be carefully designed and built as an integral part of the overall generation system. Many cost trade-offs exist between system capital cost and operating efficiency. Careful cost-optimization studies must be performed to design and size the overall facility, including the dry cooling system as well as the production system. For this reason, it is impractical, or at least prohibitively expensive in terms of dollars and other resources required to attempt to add dry towers to an existing plant.

Because of all these reasons, the use of dry-tower systems is abhorrent to most persons who are well-acquainted with the electric power industry. On the other hand, many environmentalists believe that such towers are the only acceptable solution to the "thermal pollution problem". The future of dry-cooling towers for power-generation facilities in the U.S. is undecided. The eventual outcome will have significant implications for everyone.

Cooling System Costs

In the long range planning for large-scale power systems, there will always exist a certain amount of uncertainty in estimating the costs of alternative cooling systems; the best one can hope to do is minimize that uncertainty to acceptable levels. Such uncertainties arise from a number of factors, including future performance requirements, technological break-throughs in techniques and materials, inflation, and indirectly from regulations such as Occupational Safety and Health Act (OSHA), etc.

The uncertainty decreases with the size of the system under consideration and the state of the planning/design process. Estimates of the total cost necessary to attain the zero-discharge requirement for all power generation in the U.S. between now and the year 2000 must be considered rough at best, possibly plus or minus 100-200 percent or more. On the other hand, the estimates of cooling-system cost for a specific plant in the advanced stages of design should be within a few percent of the actual costs. For a 30-year planning horizon and a specific sub-state region with one principal load center, with only a few feasible cooling alternatives available due to local conditions, the reliability of the cost estimates would fall between the above bounds.

Most information that has been reported in the literature can be put into one of two categories, either broad-based projections on a national basis or case studies of a particular plant. Ample generalized data are available, but specific case history data are scarce. This scarcity is caused by two compounding factors. Normal accounting procedures do not differentiate between dollars spent on cooling and non-cooling parts of the facility, a fact which makes accurate cost reporting of the cooling systems difficult. Then too, most utilities are not eager to distribute cost information because such action is almost certain to generate criticism over rates, etc. For corporate planning purposes, utilities develop internal estimates of the many alternatives; however, these estimates generally are not available to outsiders.

Studies and estimates of increased dollar costs under various thermal pollution control policies have been conducted. One representative study (Cheney and Smith, 1969) was done by the Travelers' Research Corporation for the National Coal Policy Conference. The purpose of the overall study was to

> "provide a broad system overview of the production and disposal of waste heat within the thermoelectric generation process;... and form the basic framework within which such an evaluation can proceed..."

Probable overall costs to the power generating industry were determined based on various waste-heat discharge policies that might be adopted by the federal government. Three basic policies were postulated and costs developed. The policies were a "pristine pure policy", a "nondegradation policy", and a "practical maximum policy". (See previous discussion, Section III.2) The authors of that report emphasized that the results must be considered only as "order of magnitude" estimates because of emerging technology, local cost variations, environmental conditions, ambiguous state of governmental regulation, and the differences within the industry.

Obviously, for any national study, the development of rational heat-control-abatement programs for each plant, computation of individual costs, and summation of these costs to get a total national cost are virtually impossible. Therefore, several broad assumptions about the reaction of the industry as a whole to meet future standards is necessary. The costs of this general reactive abatement program must be computed and applied industry wide. While the overall results should be representative, it would be misleading and improper to apply such data to an individual plant, or even a single utility system.

In addition to the three policy assumptions previously mentioned, the Cheney and Smith estimates were based on the use of MD evaporative cooling towers used either as supplemental cooling devices or in a closed-cycle system. Even though the authors readily recognized that not all cooling would be provided by MD evaporative towers, they contended that the aggregated estimates were sufficiently realistic for their purposes.

The results of the Cheney and Smith study are summarized in Table IV.2C. The cost predictions for total industry expenditures on thermal pollution abatement range from a low of $2.46 billion to a high of $6.85 billion. Unfortunately the published report of Cheney and Smith did not discuss the unit cost data from which these figures were developed. While such nationally aggregated data may not be of any direct use to this investigation, the data do provide some insight into the magnitude of the overall problem on a national basis and illustrate the type of information which is frequently published in the literature.

Recent Federal Power Commission studies reported in the Nuclear Forum (Warren, 1970) have been conducted along similar lines; i.e., using three assumptions about the level of required environmental controls. (See Section III.2 for discussion) Warren's basic assumptions are somewhat similar, ranging from a reliance on simple once-through cooling wherever possible to closed systems for all plants, both new and old.

COOLING ALTERNATIVE	TIME PERIOD	GENERATION AFFECTED (BILLIONS KWH)	ANNUAL COST OF ABATEMENT (MILLIONS OF $)
(A) "PRISTINE-PURE"	1970	1,038	473
	1980	2,105	847
	Σ'70-'80	16,672	6,855
(B) "NON-DEGRADATION"	1970	249	76
	1980	1,482	533
	Σ'70-'80	8,898	2,952
(C) "PRACTICAL MAXIMUM"	1970	364	138
	1980	1,449	346
	Σ'70-'80	7,905	2,464

ESTIMATED TOTAL NATIONAL ANNUAL COST ESTIMATES FOR THERMAL POLLUTION ABATEMENT FOR 1970-1980 UNDER VARYING PUBLIC POLICIES

(AFTER CHENEY & SMITH, 1969)

TABLE IV. 2C

These data which are summarized in Table IV.2D indicate that between now and the year 2000, the industry will spend somewhere between \$5.5 and \$9 billion to dispose of waste heat, which will total more than 15,500 trillion (15.5×10^{15}) BTU's, an amount equal to about 2.7 billion barrels of oil. For the 1970-1980 period, these figures range between \$1.8 and \$4.1 billion, which is somewhat lower than the total national cost estimates of \$2.46 and \$6.85 billion developed by Cheney and Smith. The difference is most noticeable when the tightest environmental control policies are implemented. This difference is partially explained by Cheney and Smith's exclusive reliance on MD evaporative towers, while Warren used a mixture of towers and ponds and in some cases, deep ocean outfalls to achieve the required cooling. Taking these basic differences into account, the two studies are in general agreement. Warren makes a cautioning statement about his results which is applicable to all such studies:

> "...the resulting figures produce no significant (quantitative) conclusions. They do, however, give an idea of the gross magnitude of investment in cooling facilities and the impact on power costs of this phase of environmental protection...continual assessment of the benefit-to-cost ratio--with the broadest possible interpretation of 'benefits' and 'costs'--will provide the best guide for decisions in critical judgment cases..."

A study by Dynatech (1969) prepared for the Environmental Protection Agency consisted of a survey of alternative cooling methods including the pros, cons, and estimated costs of each. This study produced a wide variety of individual cost data, as well as discussions of the various cooling systems. The last section of that report developed a set of tables which gave the comparative capital, operating, maintenance, and total costs, and added cost to the consumer, for eleven different cooling schemes for 10°F and 20°F condenser rises for both fossil-fueled and nuclear plants. The eleven alternatives included:

(1) Once-Through Run-of-River

(2) Once-Through: Estuary

REGION	$ MILLION 71-80	81-90	TOTAL
NORTHEAST			
A	335	620	955
B	435	810	1305
C	815	895	1710
EAST CENTRAL			
A	255	430	685
B	335	615	950
C	670	615	1285
SOUTHEAST			
A	415	775	1190
B	535	940	1475
C	985	955	1940
WEST CENTRAL			
A	185	390	575
B	255	640	895
C	495	655	1150
SOUTH CENTRAL			
A	275	540	815
B	345	740	1085
C	510	755	1265
WEST			
A	390	835	1225
B	405	1055	1460
C	625	1060	1685
NATIONAL TOTALS			
A	1855	3590	5445
B	2310	4860	7170
C	4100	4935	9035

ESTIMATED TOTAL NATIONAL COOLING COSTS FOR 1970-1990 (AFTER WARREN, 1970)

TABLE IV.2D

(3) Cooling Pond

(4) Spray Pond

(5) ND Wet Tower with River Makeup

(6) ND Wet Tower with Reservoir Makeup

(7) MD Wet Tower

(8) ND Dry Tower

(9) MD Dry Tower

(10) Evaporative Condenser

(11) Air-Cooled Condenser

The reported data for a 1000 MW nuclear-fueled plant with a condenser ΔT of $20^{\circ}F$ are summarized in Table IV.2E. A number of assumptions about plant efficiency, water availability, local meteorological and geological conditions, construction costs, and other factors were made. The calculations were based on heat rejection rates of 6410 BTU/KWH for the nuclear units and 3840 BTU/KWH for fossil units. The resulting overall efficiencies were 33 percent for the nuclear plant and 40 percent for the fossil-fueled plant.

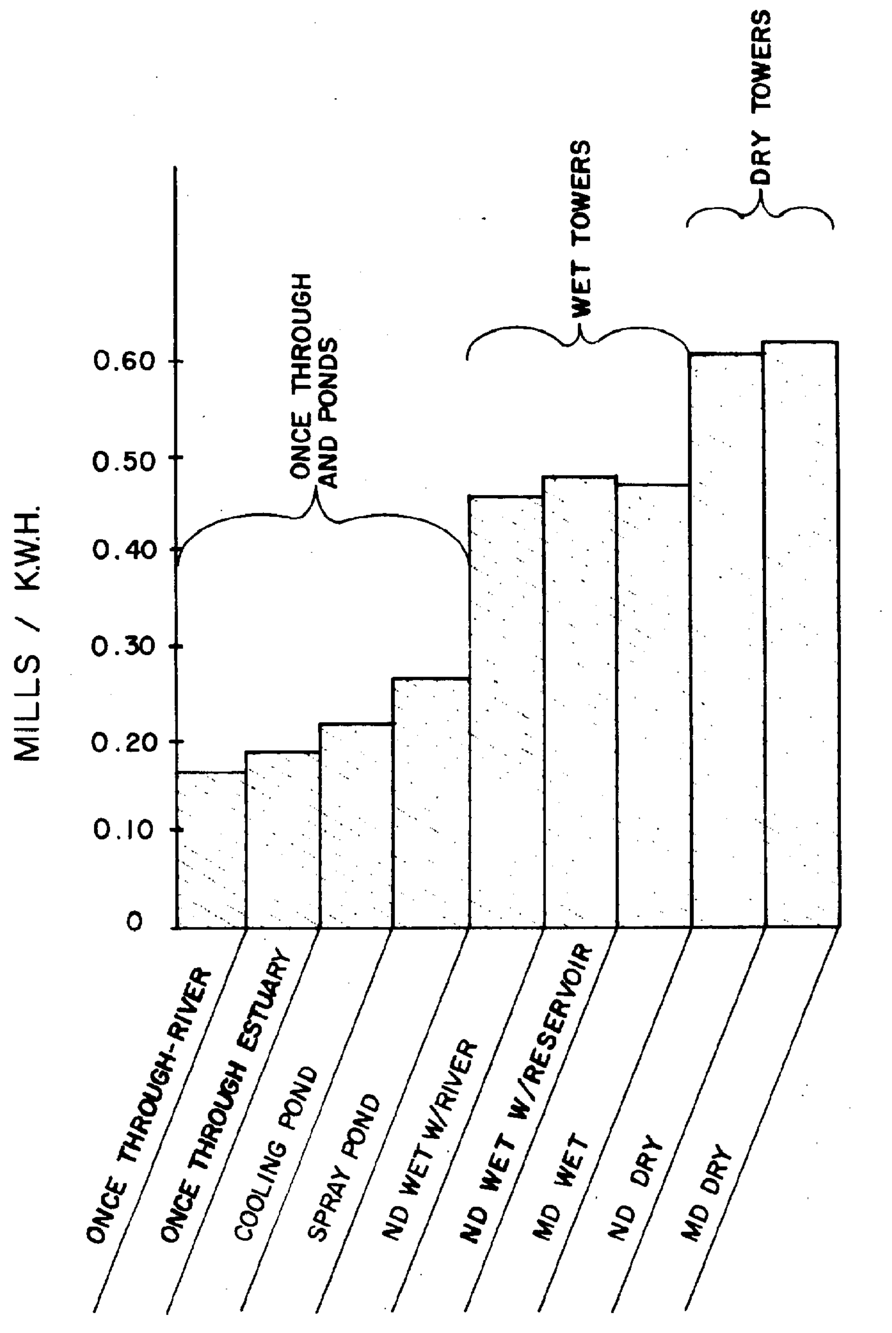
The Dynatech results were generalized over the entire country, and did not consider the regional conditions of any particular study area; however, a few of the observations are still illuminating. The lowest costs were incurred with once-through systems and the highest were for dry towers; with ponds, evaporative towers and spray ponds falling in between. Comparative cost data were generated and presented for evaporative condensers and air-cooled condensers for the hypothetical 1000 MW plant, even though the text specifically states that such devices never have been built in sizes large enough for even a small power plant. For this reason, these data must be considered purely speculative.

The relative costs of the alternative systems are compared graphically in Figure IV.2H. The value is a total unit cost in mills/KWH, which includes

	CAPITAL COSTS $/KW	OPERATING COST $/KW-YR	MAINTENANCE COST $/KW-YR	TOTAL COST $/KW-YR	ADDITIONAL COST TO CONSUMER PER KWH	TOTAL UNIT COSTS MILLS/KWH
ONCE THROUGH - RIVER	5.24	0.50	0.50	1.47	0	0.168
ONCE THROUGH - ESTUARY	6.24	0.50	0.50	1.56	0.05	0.178
COOLING POND	7.50	0.62	0.62	1.92	0.26	0.219
SPRAY POND	8.10	1.00	0.50	2.23	0.43	0.255
ND WET TOWER - RIVER	11.50	1.00	1.00	4.08	1.49	0.466
ND WET TOWER - RESERVOIR	14.00	1.00	1.00	4.31	1.62	0.493
MD WET TOWER	9.40	1.33	1.33	4.20	1.56	0.480
ND DRY TOWER	22.0	1.00	1.00	5.38	2.24	0.615
MD DRY TOWER	15.0	1.33	1.33	5.41	2.26	0.618
EVAPORATIVE CONDENSER	13.0	1.40	1.40	4.67	1.83	0.534
AIR COOLED CONDENSER	17.0	1.00	0.50	4.43	1.70	0.506

RELATIVE COSTS OF ALTERNATIVE COOLING SYSTEM FOR NUCLEAR PLANT WITH $\Delta T = 20°F$ (AFTER DYNATECH, 1969)

TABLE IV.2E



COMPARATIVE COSTS OF ALTERNATIVE COOLING METHODS (AFTER DYNATECH-1969)
FIGURE IV. 2H

an amortized annual capital cost (30 years at 9 percent, plus operation and maintenance).

In Figure IV.2H, the cooling costs for the alternatives discussed fall into three distinct categories: once-through plus ponds, wet towers, and dry towers. The cost of wet towers is about double that of once-through systems and ponds, while dry towers are about 50 percent more expensive than wet towers, or about three times the cost of the cheapest alternative. These are generalized data based on aggregated and/or averaged parameters; however, these general relationships are probably valid for most locations, unless some particular local condition excludes one of the alternatives.

A rough comparison of these data with those of the earlier cases (Cheney and Smith, 1969; and Warren, 1970) is enlightening. Cheney and Smith, in order to achieve the "pristine pure" condition estimate a total outlay of \$6.8 billion between 1971 and 1980, based on 16.6×10^{12} KWH being affected by abatement measures. If one takes the Dynatech figures for ponds (approximately 0.20 mills/KWH) and wet towers (approximately 0.50 mills/KWH), and assumes that each system will be used for half of the facilities, the average cost would be 0.35 mills/KWH. Multiplying this by the number of KWH projected (16.6×10^{12}) gives an estimated cost of \$5.8 billion, which is fairly close to Cheney and Smith's estimate of \$6.8 billion. Warren's data for the same period indicate that about \$4.1 billion would be spent. Thus, considering the coarseness of the projections, and the many assumptions implicit in each, all three sets of data are reasonably comparable.

These data give a good general picture of what can be expected on a broad national basis, but are still somewhat "coarse" for application to a specific power system which covers only a part of Texas and will produce substantially less than 1 percent of the nation's power. Several options were available for obtaining improved data estimates. The three principal alternatives were:

(1) Perform an engineering analysis based upon conditions in the study region, and compute the associated costs for each cooling alternative.

(2) Go to published reports which give regional variations in meteorological conditions, building costs, etc., and attempt to develop a method to "regionalize" the national data by the use of multipliers applied to the many parameters.

(3) Approach several utilities operating in the state, and, working through the Governor's Advisory Committee on Power Plant Siting, attempt to acquire reasonable approximations of the actual system-planning data.

The last approach was chosen and proved successful. Several utility companies readily provided data on certain cooling methods which they believed were promising*.

A summary of these cost data is given in Table IV.2F. Capital and total unit costs are presented for five different systems using fresh water and salt water as applicable. All data are for nuclear plants with a 32 percent overall efficiency, since most experts do not expect any major fossil-fueled plants to be built in South Texas**. However, since fossil plants produce about

* The information on this cooling-system cost data was readily obtained, though it was rather scanty. The utilities gladly share such information with each other. This is in marked contrast to other types of cost data that they consider confidential because they relate to competitive/propietrary processes/information. They are not at all reticent, however, in sharing cooling system cost data; they welcome any publicity on how expensive these extra cooling systems will be.

** During the course of this study, major natural-gas curtailments became a reality for some utilities. Also a consortium of private and public utilities announced plans for a major nuclear plant called the "South Texas Nuclear Project" to be built in the northeastern portion of the study area.

COOLING SYSTEM	FRESH WATER		SALT WATER[1]	
	$/KW	MILLS/KWH	$/KW	MILLS/KWH
ONCE THROUGH	7.44	0.18	8.08	0.19
ONCE THROUGH W/PONDS	15.41	0.20	16.05	0.21
WET TOWERS (ND or MD)[2]	11.65	0.53	NOT AVAILABLE[3]	
DRY TOWERS - ND	22.00	2.40	—	—
DRY TOWERS - MD	17.00	2.20	—	—

1. INCLUDES ESTUARINE OR BRACKISH WATER AS WELL AS SEAWATER
2. ND TOWERS ARE OFTEN SHOWN CHEAPER THAN MD TOWERS; HOWEVER, THE ADDITIONAL STRUCTURAL STRENGTH REQUIRED TO WITHSTAND 150 MPH HURRICANE WINDS MAKES THEIR COSTS THE SAME FOR THIS AREA.
3. TECHNOLOGY NOT AVAILABLE TO BUILD THESE WITHIN ACCEPTABLE DRIFT TOLERANCES.

ESTIMATED COOLING COSTS FOR
TEXAS COASTAL AREAS
TABLE IV. 2F

50 percent less waste heat per unit of electricity generated, estimated costs for fossil plants can be obtained by multiplying the costs given in Table IV.2F by 2/3.

Five options also are presented in Table IV.2F: once-through, once-through with ponds, wet towers (one figure includes both ND and MD), ND dry towers and MD wet towers. Two of these systems, once-through and once-through with ponds, can be used with either fresh or salt water. Thus, seven possible alternatives for cooling exist. The costs for each method are also given in Table IV.2F. These cost data were used in this study to determine the costs of meeting the alternative environmental constraints.

The resource requirements, or "resource costs", may often be as important as the dollar costs in selecting a heat dissipation system and evaluating its impacts. The three principal natural resource requirements of principal concern in this investigation are water supply, land requirements, and energy (i.e., fuel) consumption. In Section I.2, as each of the cooling alternatives was presented, the natural resource implications were also discussed, and when data were available, quantitative estimates of the resource requirements were presented.

Table IV.2G contains a set of "resource costs" analogous to the "dollar costs" of various cooling techniques shown in Table IV.2F. These data, derived from a variety of sources discussed in the previous section, will be used later in Section V.3 for computing the total natural resource "costs" required to satisfy the heat dissipation strategies under the various growth and cooling policies.

Thus, in summarizing the power plant cooling situation as it impacts upon this project, the following conclusions can be drawn:

	WATER (1) THRU-PUT (GAL./KWH)	CONSUMPTIVE USE(GAL./KWH)	LAND (2) AC/MW	ENERGY (3) KWH/10^3KWH
ONCE-THROUGH	30 - 50 (40)	0.2 – 0.3 (.25)	—	1.33
COOLING PONDS	30 - 50 (40)	0.2 –0.3 (.25)	1.5	1.50
WET TOWERS-MD	40	0.75	0.5	4.00
DRY TOWERS-MD	—	—	0.8	16.00

1. TYPICAL PUBLISHED FIGURES.

2. THE 1.5 AC/MW IS GENERALLY ACCEPTED FIGURE FOR NUCLEAR FACILITIES; THE 0.5 AC/MW FOR WET TOWERS INCLUDES TOWER SITE AND IMMEDIATE SUPPORTING EQUIPMENT WITH NO SIGNIFICANT RESERVE FOR DRIFT ALLOWANCES; THE 0.8 AC/MW FOR DRY TOWERS IS AN ESTIMATE WHICH INCLUDES TOWER SITES WITH SOME SPACING TO PREVENT AIR INFLOW INTERFERENCE.

3. DEVELOPED FROM DYNATECH, 1969

ESTIMATED RESOURCE REQUIREMENTS FOR ALTERNATIVE COOLING TECHNIQUES
TABLE IV. 2G

(1) Numerous cooling alternatives exist on paper, but practical realities such as costs, adverse secondary impacts, other limiting resources, etc. combine to narrow the feasible options for any given system or specific facility to very few options.

(2) For a given location, any set of environmental constraints generally can be met if one is willing to pay the resulting costs.

(3) A cooling system which meets one rigid set of environmental constraints, must be selected with considerable caution to insure that the solution chosen does not create secondary problems potentially worse than the waste-heat problem.

(4) Numerous methods could have been used to develop cooling cost estimates for this project. Several, including "regionalization" of nation-wide data and detailed cost estimates developed from hypothetical specific plant designs were considered. The method of obtaining, through the Governor's Advisory Committee on Power Plant Siting, actual planning data from several utilities in Texas, provided the most accurate information. Also it had the added benefit of convincing persons that the results were realistic and might have real world applicability.

IV.3 THE FUEL SITUATION

Some significant changes in the facts and attitudes about alternative fuels for electric-power generation have occurred during the last three years. As recently as two years ago, a general feeling prevailed among both the public and many utility officials that fossil fuels would continue to be the principal energy source.

Natural gas is about the "ideal" boiler fuel, because of its low cost, ready accessibility, and clean-burning nature. It has always been the predominant fuel in Texas, accounting for more than 90 percent of the state's electrical power. And Texas has long been a leader in gas production. Many believed that natural gas, occasionally supplemented by fuel oil, would continue for many years as the principal fuel in Texas. This situation, however, is rapidly changing as competing demands, price increases, and mandatory allocation programs all occur. The cumulative effect will be a decrease in the use of gas as a boiler fuel.

Some corporate planners who tried to sound the alarm were met by strong resistance from management, the general public, and public agencies. The current energy situation has created a public awareness, that changes in energy production, movement, and usage are inevitable in the near future. Several companies in Texas have announced plans for large nuclear facilities. One major lignite plant recently went on-line, and other options are being explored by various utilities. The fuel situation in Texas is changing from gas-dominated systems to a broader base, with coal holding some promise. The major trend, however, is toward nuclear power.

Alternative Fuel Sources

Fuel oil is currently used in limited quantities, principally as an emergency back-up fuel to natural gas, even though gas-fired plants are being built/converted to permit the use of oil. Many factors, however, prevent oil from becoming a probable major new fuel source, such as rapidly dwindling domestic resources, competition for available supplies, cost, environmental constraints on air emission, and the very questionable reliability of foreign sources.

Coal is an attractive possibility. Texas does not have any high-grade bituminous coal resources, but a significant band of lignite deposits crosses the state from Texarkana in the Northeast to Del Rio in the Southwest. These deposits are scattered, but some are shallow enough to be economically recovered with strip mining methods. Experiences with the existing plants at Fairfield and Rockdale have proved that strip mining can be done in the flat Texas countryside without any environmental damage if proper procedures are followed. Extensive air pollution control equipment also has been used to eliminate most undesirable atmospheric emissions. Thus, lignite does offer a possible long-term fuel source.

Nuclear energy is now considered by most experts to be the most probable energy source for electrical power generation. The Governor's Advisory Committee on Power Plant Siting quotes estimates predicting that by 1985 Texas will have an installed nuclear capacity of 15,000 MW. Current total operable U.S. facilities total 13,260 MW. Almost without exception, all utilities in Texas now appear to be favoring nuclear plants. Within the last year, four major nuclear proposals, totaling more than 17,600 MW, have been announced. At this time, most proposals favor a light water reactor, but developments with the first full-scale, high-temperature gas-cooled reactor being completed and tested at Fort St. Vrain in Colorado are being carefully watched. Unfortunately, the fuel supply for nuclear reactors is more limited than most persons realize. The nuclear fission process is dependent on development of the breeder reactors if nuclear energy is to become a viable long-term energy source.

Many other possibilities exist, but at this time most of these have seemingly insurmountable technical and economical obstacles that must be overcome. Fusion offers an attractive possibility because the fuel source is essentially unlimited. The nature of the process makes a plant completely fail-safe with only negligible quantities of radioactive waste being produced. Unfortunately, fusion research, after many years and millions of dollars, is still only in an embryonic state.

While solar energy is much lauded by some, the technical and economic constraints appear to preclude the sun as a viable centralized power source.

However, modified building designs could enable direct use of solar heating/cooling which would significantly reduce electrical demands for these uses.

Other alternative sources such as geothermal, fuel cells, synthetic natural gas, topping cycles, etc., offer some relief at some point in time, but cannot be counted on to either meet a significant amount of the new energy demands or to handle any significant amount of the petroleum demands.

Thus, the following points concerning future fuel supplies that pertain to this project can be concluded:

(1) Natural gas will become scarcer as a boiler fuel; it is no longer realistic to expect gas to be available to meet any new electrical generation requirements.

(2) Fuel oil may be used in the short run, but must not be viewed as a long-range alternative.

(3) Lignite offers a possibility, but is not favored because of the difficulties in coping with air-pollution and related strip mining impacts. The importation of coal from the northern Rocky Mountain States is being considered, but it would still require the same cooling water.

(4) Fusion offers an attractive long-term solution, but is not expected to be operational much before the Twenty-first century.

(5) Nuclear fission appears to be the most likely prime-energy source for power generation during the rest of the Twentieth century.

(6) For the purposes of this study, all new power-generation facilities are assumed to be nuclear fission plants.

IV.4 TRANSMISSION CONSTRAINTS

The principal role of transmission facilities is to move electricity from the generating plant to the load centers. Transmission lines also play a vital, but frequently overlooked, role, by interconnecting major systems and thus providing redundancy and increasing reliability. Such long-distance inter-ties permit exchange of power on an interregional basis, thereby saving on the generating facility investment*.

As in all other components of the electrical-utility industry, technological progress has been substantial; transmission facilities and operations have been greatly improved by new materials, improved methods, and the advent of computerized system-load centers. However, despite these improvements, the transmission system required still plays a significant role in power plant siting.

Two extreme attitudes can be adopted when considering the impact of power plant siting on transmission requirements. One attitude calls for locating the generating plant at the fuel source, whereas the other maintains that the plant should be located at the load center. Mine-mouth located, coal-fired plants, such as the Fairfield "Big Brown" plant and the "Four Corners" complex in New Mexico are examples of mine-mouth plants. In these cases the other resources required for generation, principally ample water and cheap land, were available, and economics indicated that power transmission to the load centers would be more favorable than transporting the coal to plant sites nearer the load centers.

* While this is done in some parts of the U.S., it is worth noting that the member companies of the Texas Inter-connected System are required to meet all their own demands, plus keep a spinning reserve of about 13-14 percent just for emergencies. This eliminates interdependence except under emergency conditions.

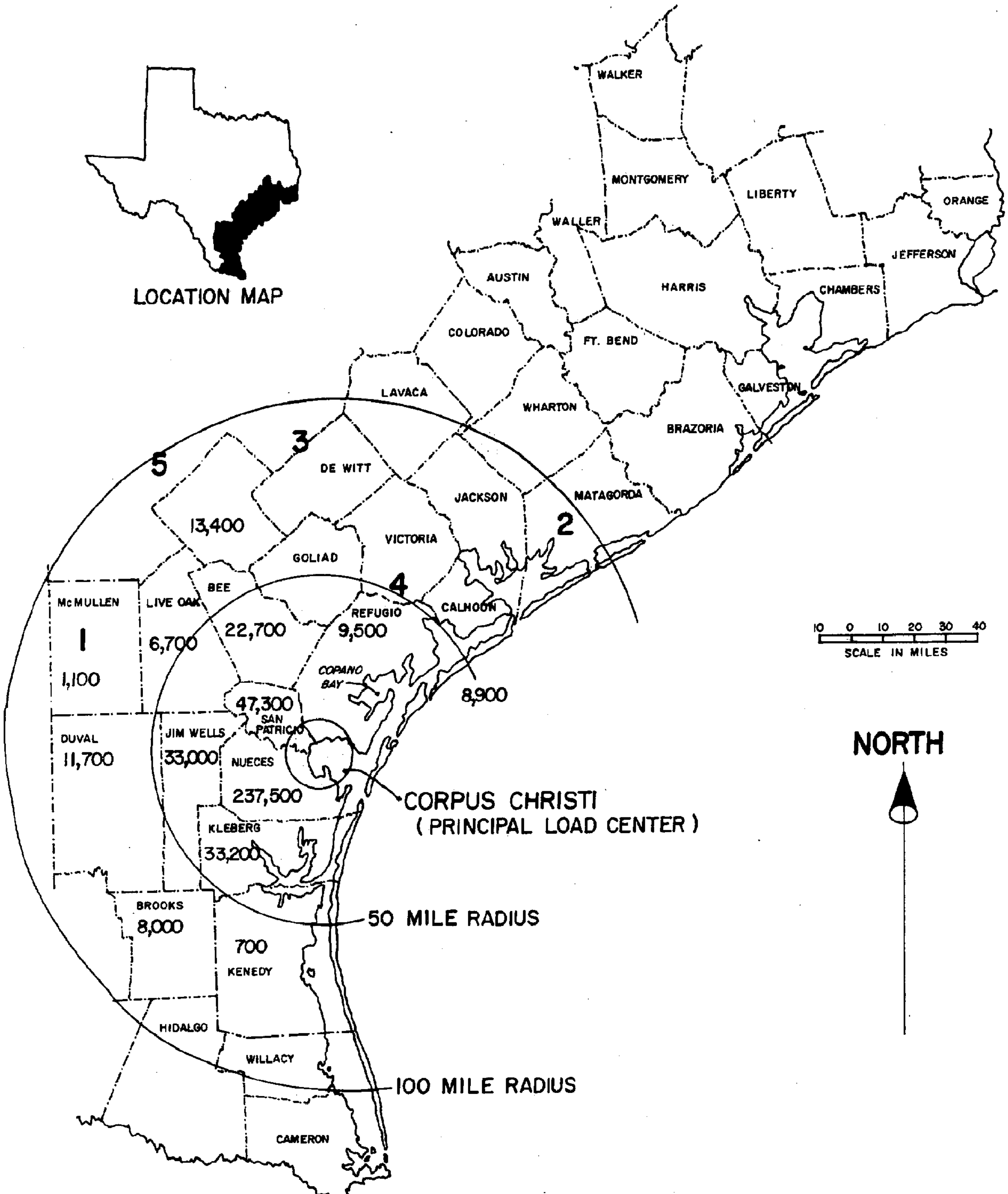
A tendency to locate as near to the load centers as possible has been prevalent in Texas. The ease with which natural gas can be moved was a major reason for this. Also, in Texas, many load centers are located on coastal waters or on inland reservoirs which simplified the situation further by providing the necessary cooling water.

In the last few years there has been a reversal from the tend of locating the plants at the load centers. This could be attributable to the increased public concern over plant location, associated with a reluctance to have a power plant for a neighbor. Also the rapidly increasing land values near most growth areas have made land costs prohibitive. Then too, as nuclear power replaces gas, there will be a further impetus to locate the plants in sparsely populated areas because of safety reasons.

Transmission considerations, however, are not likely to play a major role in the siting of power plants in the region included in this study. A map of the entire Texas Coastal Zone is presented in Figure IV.4A. The study area is shaded. The principal load center, accounting for approximately 85 percent of the area's electrical demands, is in the Corpus Christi standard metropolitan statistical area. The map indicates abundant coastal waters that are readily accessible if water-quality regulations permit their use.

If low-population areas are required because of increased nuclear safety, or in the case of the need of building large dry towers for aesthetic reasons, numerous sites with low-population can be located nearby. The numbers in parentheses in each county indicate the 1970 population.

If availability of fresh water is a determinant, several close options exist. These alternatives are shown in Figure IV.4A as circled numbers which identify a feasible reservoir site or location for an off-channel cooling pond. It is worth noting that site "4" has recently been chosen by a consortium of



TRANSMISSION
DISTANCES TO PRINCIPAL LOAD CENTER

FIGURE IV. 4A

electric utilities as the location of a 4400 MW nuclear facility; fresh water availability was given as a prime reason for selecting that site.

The arcs included on Figure IV.4A indicate distances of 50 and 100 miles from the principal load center, and show that an ample assortment of alternatives exist at a reasonable distance. The rural nature of the area, with ranch and pasture land predominating, will minimize any significant conflicts between transmission right-of-way and other land uses. The possibility of hurricane damage to such facilities presents a threat about which nothing can be done at this time.

Differential transmission costs over the distances being considered between possible generating sites in this study are low enough to be considered negligible.

Several conclusions can be drawn concerning the influence of transmission considerations on this investigation:

(1) Alternative sites, which can satisfy a wide variety of conditions, are available within a 100 miles radius of the principal load center; transmission facilities will not be a major factor in power plant siting decisions in this investigation.

(2) For the distances being considered, differential costs of transmission are minor compared to cooling costs, and will not have a significant impact on the results of this study; therefore, transmission costs can be ignored without affecting the purposes or outcome of this analysis.

CHAPTER V
RESULTS AND ANALYSIS

Thus far in this report, alternative growth and environmental policies have been developed (Section II.1-2), and cooling options and their respective costs were presented (Section IV.2). In the important second chapter, the need for an analytical approach was discussed and developed (Section II.6); and a step-by-step analytical methodology was presented along with a greatly simplified example problem (Section II.7). The six principal steps and two sub-steps which comprise that overall analytical procedure were given in Figure II.7A.

This chapter combines the quantified policies, with the appropriate technical background information, and takes them the final step, by performing the analyses which are the central objective of this investigation. This analysis is done in five principal sections:

(1) Allocation of energy requirements among available cooling alternatives in compliance with established public policies;

(2) Computation of costs for satisfying each projected condition;

(3) Determination of the natural resource requirements to satisfy each projected condition and a discussion of major implications;

(4) Determination of the regional economic impact of cost increases as shown by the regional input-output model; and

(5) An overall appraisal of the institutional, socio-economic, and political implications of the various options.

V.1 ALLOCATION OF PROJECTED REQUIREMENTS

It is necessary to allocate the projected generating requirements in accordance with the specified cooling policies. Both annual energy generated (KWH/CAP/YR), as given in Figure III.1D, and total installed generating capacity (MW), as shown in Figure III.1F, must be considered. These two figures supply the above data for the three projected levels, ZPG, INT, and COC, through the year 2000. The generating capacity and annual production must be distributed among the available cooling techniques so as to comply with the three cooling policies developed in Section III.2. These cooling policies range from the continuation of present practices, and only meeting certain localized criteria (C_1), to a "zero discharge" policy which would eliminate all disposal of waste heat into the aquatic environment (C_3). A third, intermediate policy which would restrict total heat releases to present levels (C_2) is also investigated.

The first step in this allocation process is to develop a quantifiable "strategy" for achieving each cooling policy. These strategies are essentially plans for using particular cooling processes on specified fractions of the system's generating capacity. Under certain policies, this allocation strategy will principally involve installing cooling devices on new units, whereas under other circumstances the strategy will require the addition of cooling devices to existing facilities. Other conditions will involve a combination of new and add-on equipment. To satisfy each policy condition it is necessary to quantitatively determine by a series of steps what portion of the total capacity is to be assigned to the various cooling methods. A specific procedure is given and discussed for each policy.

<u>Cooling Option A</u> (C_1) - Continue present practices, subject to satisfying localized discharge criteria. The following four-part strategy is proposed to meet this liberal policy:

(a) All existing units continue operating "as is",

(b) Assign 50 percent new capacity to once-through,

(c) Assign 25 percent new capacity to ponds,

(d) Assign 25 percent new capacity to wet towers.

This strategy is based on the assumptions that existing facilities will be permitted to operate; enough acceptable sites exist for once-through cooling, using either salt or fresh water, to handle half of all projected needs; and ponds and wet towers will be used about equally on future additions where once-through cooling is not acceptable.

Cooling Option B (C_2) - Freeze the total heat discharge (BTU/day) at current levels. To achieve this goal a five-part strategy is used:

(a) All existing units on either cooling ponds or wet towers continue operating "as is",

(b) Allow 50 percent of existing once-through units to continue as they are now,

(c) Convert the other 50 percent of existing once-through units to wet towers,

(d) Assign 50 percent of the new capacity to ponds,

(e) Assign 50 percent of the new capacity to wet towers.

In order to hold the total heat discharge at present levels, it will be necessary to either require zero discharge on all new units, or to add some additional cooling capability to existing plants. Based upon current industry practice and a knowledge of current facilities in the region, the above strategy seems realistic because it would be easier to convert some existing facilities to fresh water towers rather than to ponds; dry towers would be avoided if at all possible; and, at the candidate new sites in the area, there are several places where ponds would be preferable and several instances where fresh-water towers probably would be selected.

Cooling Option C (C_3) - This policy calls for "zero discharge", i.e., the elimination of all waste-heat discharge to the aquatic environment.

To satisfy this strict policy, a six-part strategy would be used:

(a) All existing units on either cooling ponds or wet towers continue operating "as is",

(b) Convert 50 percent of the existing once-through units to cooling ponds,

(c) Convert the other 50 percent of the existing once-through units to wet towers,

(d) Assign 25 percent new capacity to ponds,

(e) Assign 50 percent new capacity to wet towers,

(f) Assign 25 percent new capacity to dry towers.

The rationale behind this strategy stems from the following assumptions: in order to convert all existing once-through units to some other cooling process, both wet towers and ponds will be used; some new units can go on ponds, and some will almost certainly use dry towers, but the bulk of the new facilities, under "zero-discharge" conditions, will use wet towers.

The above strategies are certainly not the only possible ones that could be used to satisfy the three cooling policies. However, after investigation of the present situation and consideration of available alternatives, plus discussions with utility officials, these strategies seemed as realistic as any which could be anticipated at the present time. Uncertainty is always inherent in anticipating how the private sector will react technically in order to comply with any sort of governmental regulation. This uncertainty is particularly true in the electric power industry where the planning horizon is long and many factors, e.g., consumer demand, public attitudes, fuel problems, technological breakthroughs, are always present. Only one thing is certain: no projected conditions will ever exactly be encountered; rather, such projections can only give a reasonable, realistic approximation of future circumstances. Those who might believe otherwise are only fooling themselves.

The projected requirements developed in Section III.2 were distributed among select cooling methods according to the above stated criteria; the results are shown in Figures V.1A - V.1C for the period 1970 - 2000. The computations were done on time steps of five years rather than annually, since any projections beyond 8-10 years are simply not accurate enough to realistically predict whether a demand will materialize in 1987 or 1989. The many uncertainties facing the power industry, ranging from fuel availability to unpredictable environmental restrictions, also would make a 30-year annual analysis largely a number-generating exercise. For the purpose of illustrating the long-term implications of public policy decisions, the seven points in time given by five-year intervals between 1970 and 2000 provide ample resolution. On the other hand, 31 points would only add more numbers without contributing any significant additional information.

Figure V.1A shows the projected distribution of generating capacity by cooling process used. Each 3 x 3 matrix represents one point in time. Each cell within that matrix represents one possible combination of growth level and cooling policy. The four numbers within the cell give the generating capacity utilizing each cooling technique: the first number in the cell refers to once-through cooling, the second to ponds, the third to wet towers, and the fourth to dry towers. Figures V.1B and V.1C are similar but show the distribution of annual energy production as percentages rather than installed generating capacities.

For example in Figure V.1A, cell 5, which represents the intermediate (INT) growth policy and the C_2 cooling policy, shows a total 1970 generating capacity of 1680 MW, to be distributed among once-through (350 MW) and wet towers (1330 MW) with neither ponds nor dry towers being used. Similarly, in 1990 this same cell indicates that once-through is still used on 350 MW, wet towers are used on 2690 MW, and ponds account for 1360 MW. Dry towers are still not used in meeting the total generating capacity of 4670 MW.

1970

ZPG	700 0 980 0	350 0 1330 0	0 350 1330 0
INT	700 0 980 0	350 0 1330 0	0 350 1330 0
COC	700 0 980 0	350 0 1330 0	0 350 1330 0

1975

1010 155 1135 0	350 310 1640 0	0 505 1640 155
1010 155 1135 0	350 310 1640 0	0 510 1640 160
1060 180 1160 0	350 360 1690 0	0 530 1690 180

1980

1310 305 1285 0	250 610 1940 0	0 655 1940 305
1370 325 1305 0	350 660 1990 0	0 680 1990 330
1410 350 1340 0	350 710 2040 0	0 700 2040 360

1985

1580 445 1425 0	350 890 2210 0	0 795 2210 445
1730 495 1475 0	350 1010 2340 0	0 860 2340 500
1810 550 1540 0	350 1110 2440 0	0 900 2440 560

1990

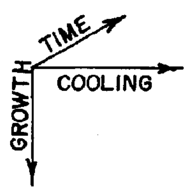
1510 555 1535 0	350 1110 2440 0	0 905 2440 555
2090 665 1645 0	350 1360 2690 0	0 1030 2690 680
2240 760 1750 0	350 1540 2860 0	0 1110 2820 770

1995

1810 555 1535 0	350 1110 2440 0	0 905 2440 555
2190 715 1695 0	350 1460 2790 0	0 1080 2790 730
2390 840 1840 0	350 1690 3010 0	0 1190 3020 840

2000

1810 555 1535 0	350 1110 2440 0	0 905 2440 555
2240 745 1715 0	350 1510 2840 0	0 1110 2840 750
2560 930 1910 0	350 1860 3190 0	0 1280 3190 930



1	4	7
2	5	8
3	6	9

CELL CODE

KEY

N_1 N_2 N_3 N_4

N_1 = ONCE THROUGH
N_2 = PONDS
N_3 = WET TOWERS
N_4 = DRY TOWERS

(KWH x 10^6)

DISTRIBUTION OF GENERATING CAPACITY BY COOLING TECHNIQUE MW/METHOD
FIGURE V. 1 A

1970

ZPG	1720 0 2360 0	850 0 3230 0	0 860 3220 0
INT	1720 0 2360 0	850 0 3230 0	0 860 3220 0
COC	1720 0 2360 0	850 0 3230 0	0 860 3220 0

1975

2440 390 2720 0	720 830 4000 0	0 1220 3940 390
2480 390 2760 0	850 730 4050 0	0 1240 4000 390
2520 460 2750 0	860 860 4010 0	0 1260 4010 460

1980

3180 770 3100 0	850 1480 4720 0	0 1560 4720 770
3340 800 3130 0	870 1600 4800 0	0 1670 4800 800
3420 910 3250 0	830 1750 5000 0	0 1740 5000 840

1985

3830 1080 3400 0	850 2140 5320 0	0 1900 5330 1.080
4200 1160 3560 0	800 2410 5710 0	0 2050 5710 1160
4350 1320 3780 0	850 2650 5960 0	0 2170 5960 1320

1990

4370 1430 3700 0	850 2670 5980 0	0 2150 6050 1300
5100 1600 3920 0	850 3290 6480 0	0 2440 6480 1700
5420 1850 4250 0	810 3860 6850 0	0 2650 6910 1960

1995

4370 1430 3700 0	850 2670 5980 0	0 2150 6050 1300
5360 1780 4000 0	870 3570 6700 0	0 2670 6700 1770
5750 2080 4410 0	860 4040 7340 0	0 2940 7220 2080

2000

4370 1430 3700 0	850 2670 5980 0	0 2150 6050 1300
5470 1830 4100 0	800 3760 6840 0	0 2720 6840 1840
6150 2230 4720 0	790 4450 7860 0	0 3140 7730 2230

TIME
COOLING
GROWTH

1	4	7
2	5	8
3	6	9

CELL CODE

KEY
N_1
N_2
N_3
N_4

N_1= ONCE THROUGH
N_2= PONDS
N_3= WET TOWERS
N_4= DRY TOWERS

($KWH \times 10^6$)

DISTRIBUTION OF ANNUAL ENERGY PRODUCED BY COOLING TECHNIQUE MILLIONS OF KWH/YR./METHOD

FIGURE V. 1B

1970

ZPG	.42 0 .58 0	.21 0 .79 0	0 .21 .79 0
INT	.42 0 .58 0	.21 0 .79 0	0 .21 .79 0
COC	.42 0 .58 0	.21 0 .79 0	0 .21 .79 0

1975

ZPG	.44 .07 .49 0	.15 .13 .72 0	0 .22 .71 .07
INT	.44 .07 .49 0	.15 .13 .72 0	0 .22 .71 .07
COC	.44 .08 .48 0	.15 .15 .70 0	0 .22 .70 .08

1980

ZPG	.45 .11 .44 0	.12 .21 .67 0	0 .22 .67 .11
INT	.46 .11 .43 0	.12 .22 .66 0	0 .23 .66 .11
COC	.45 .12 .43 0	.11 .23 .66 0	0 .23 .66 .11

1985

ZPG	.46 .13 .41 0	.10 .26 .64 0	0 .23 .64 .13
INT	.47 .13 .40 0	.09 .27 .64 0	0 .23 .64 .13
COC	.46 .14 .40 0	.09 .28 .63 0	0 .23 .63 .14

1990

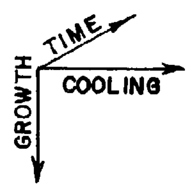
ZPG	.46 .15 .39 0	.09 .28 .63 0	0 .23 .63 .14
INT	.48 .15 .37 0	.08 .31 .61 0	0 .23 .61 .16
COC	.47 .16 .37 0	.07 .32 .61 0	0 .23 .60 .17

1995

ZPG	.46 .15 .39 0	.09 .28 .63 0	0 .23 .63 .14
INT	.48 .16 .36 0	.08 .32 .60 0	0 .24 .60 .16
COC	.47 .17 .36 0	.07 .33 .60 0	0 .24 .59 .17

2000

ZPG	.46 .15 .39 0	.09 .28 .63 0	0 .23 .63 .14
INT	.48 .16 .36 0	.07 .33 .60 0	0 .24 .60 .16
COC	.47 .17 .36 0	.06 .34 .60 0	0 .24 .59 .17



1	4	7
2	5	8
3	6	9

CELL CODE

KEY

N_1
N_2
N_3
N_4

N_1 ONCE THROUGH
N_2 PONDS
N_3 WET TOWERS
N_4 DRY TOWERS

(KWH x 10^6)

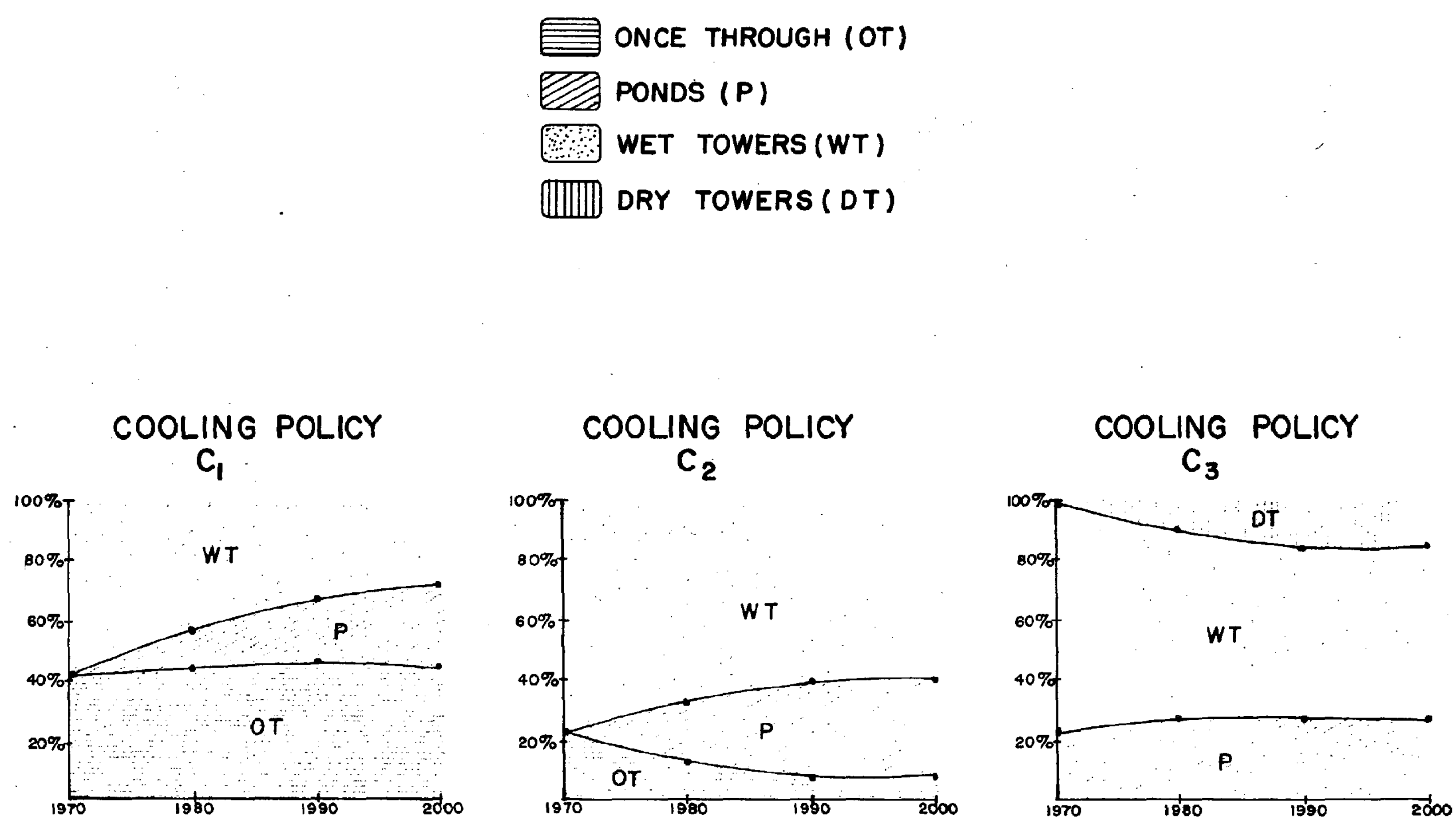
PERCENTAGE DISTRIBUTION BY COOLING METHOD
FOR BOTH MW AND KWH / YR.
FIGURE V. 1C

An adjacent cell, No. 8, which also shows the intermediate level at 1990 for the C_3 or zero-discharge policy, indicates the following: once-through is not used at all; ponds handle 1030 MW; wet towers 2960 MW, and dry towers account for 680 MW. Figures V.1A - 1C all read alike; the only difference is in the type of information given.

Figure V.1D is derived from data presented in Figure V.1C. It shows the shifts, over time, among the various cooling methods. Since these curves are percentages rather than absolute values, they apply to all projected growth levels.

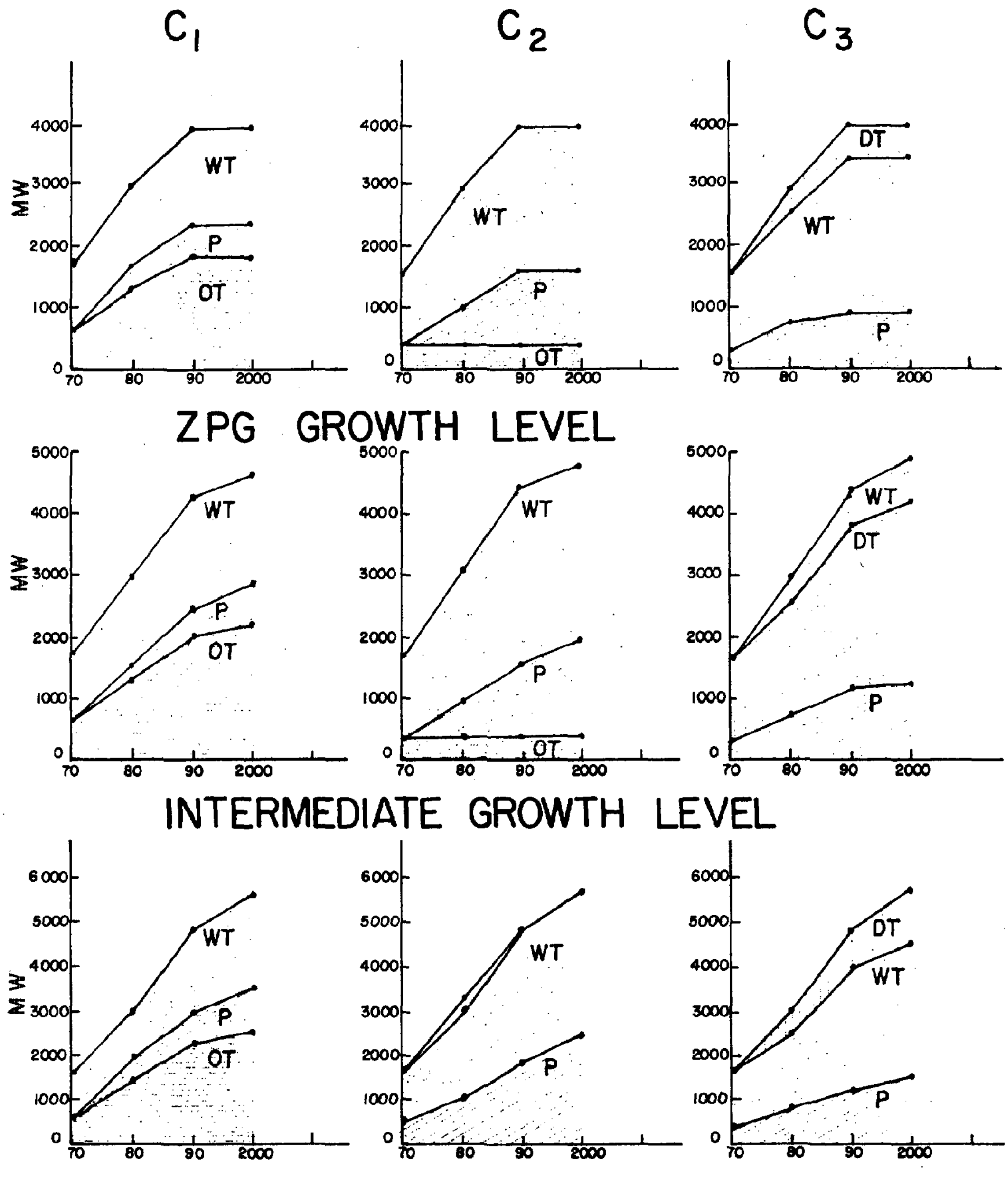
Several characteristics are worth observing from Figure V.1D. Once-through cooling is used significantly under policy C_1 but becomes minor in C_2, and is completely eliminated under C_3. Dry towers are used only under policy C_3 and, then handle far less than 15 percent of the cooling load. However, in later sections where cost and resource requirements are analyzed, even this small usage has a marked impact on operating costs and energy requirements. Ponds are significant under all policies, especially near the end of the planning horizon; however, wet towers which currently handle a majority of the heat disposal load, would continue to do so under all strategies developed in this study.

While Figure V.1D shows only the shifts in the percentages among cooling methods, the nine curves in Figure V.1E show the actual projected usages of each cooling method under the three cooling policies and the three projected growth levels. From these curves, which are developed directly from the data given in Figure V.1A, it is possible to determine the amount of generating capacity handled by each cooling process under any projected alternative future.



PERCENTAGE SHIFTS AMONG COOLING METHODS OVER TIME FOR VARIOUS COOLING POLICIES

FIGURE V. 1D



ASSIGNMENT OF GENERATING CAPACITY TO COOLING PROCESSES FOR VARIOUS GROWTH LEVELS AND COOLING POLICIES

FIGURE V. 1E

A figure similar to V.1E could be developed showing the amount of energy generated annually which is distributed by cooling techniques for each alternative future. The necessary data are given in Figure V.1B. Since the plots would be identical to those in Figure V.1E, with the only difference being the ordinate units, this curve will not be developed.

The projected alternative energy requirements have been allocated to specific cooling methods in accordance with the cooling policies established earlier in this investigation. This information may now be used to compute costs and resource requirements and to examine the natural resource and economic implications inherent in implementing the various combinations of alternative policies.

V.2 COOLING COSTS REQUIRED TO SATISFY ALTERNATIVE POLICIES

Annual cooling costs and total capital investments are readily calculated once the extent to which each cooling process used is known and the unit capital and operating costs of each process are established.

The cooling process distribution pattern for both generating capacity (MW) and annual energy consumption (KWH/YR) has been developed earlier and presented in Figures V.1A and V.1B. Costs of the alternative cooling processes were covered in Section IV.2, along with other necessary cooling information. The best available unit cooling cost estimates of the various processes for the Texas coastal regions were summarized in Table IV.2F. These unit cost data are used to compute total cooling costs.

The appropriate unit cost in Table IV.2F are multiplied by the use of Figures V.1A and V.1B to obtain the required total cooling related capital investment, and the annual expenditure attributable to cooling.

The total cooling related captial investment and the incremental increase required over each 10-year period are shown in Figure V.2A. All entries are in millions of dollars. The matrices in the first column are the total investments. The entries within each cell represent the same components as in the previous illustrations. The second column of matrices contains the incremental investment between time periods.

These figures were computed by multiplying each cell entry in Figure V.1A by the proper unit cost values and summing the products. Consider cell 5 for Period I. The entries in millions are 2.60, 10.17, 23.18, 0, and 35.95 and were obtained by multiplying the corresponding entries, 350, 660, 1990, and 0. (MW) by the proper entry from Table IV.2F and summing to get the total costs:

Once-through:	350 MW x 10^3KW/MW x 7.44 \$MW	= \$ 2.60×10^6
Ponds:	660 MW x 10^3KW/MW x 15.41 \$MW	= 10.17×10^6
Wet Towers:	1990 MW x 10^3KW/MW x 11.65 \$MW	= 23.18×10^6
Dry Towers:	0 MW	
	TOTAL	= \$$35.95 \times 10^6$

The incremental increases are found by subtracting the total investment at the end of the previous period from the total investment at the end of the present period.

Graphical presentations of the data from Figure V.2A are presented in Figures V.2B and V.2C. The upper illustration in Figure V.2B is a three dimensional plot showing the intital capital outlays required to satisfy the three environmental policies. It can be seen that \$16.63 million is required to meet the C_1 cooling policy, whereas \$20.89 million, an increase of 25 percent, would be required to satisfy the strictest policy, C_3.

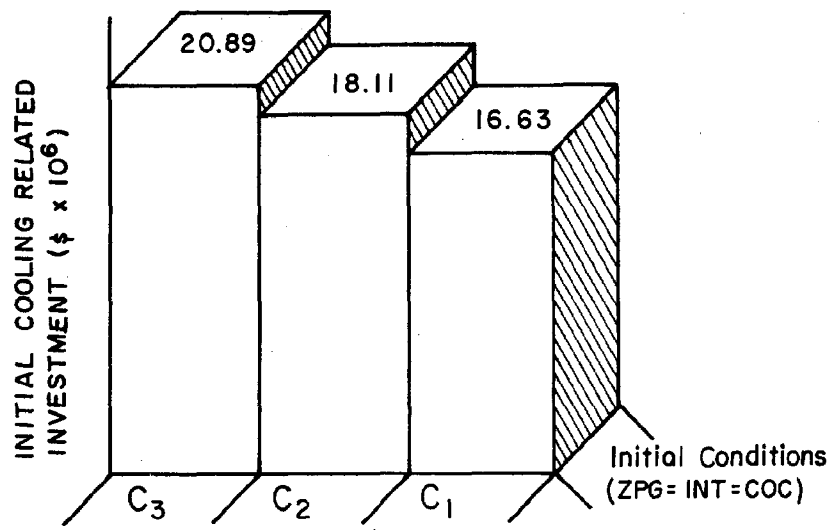
			C_1	C_2	C_3
INITIAL CONDITIONS		N_1	5.21	2.61	0
		N_2	0	0	5.39
		N_3	11.42	15.50	15.50
		N_4	0	0	0
		N_5	16.63	18.11	20.89
PERIOD I 1971 - 1980	ZPG	N_1	9.74	2.60	0
		N_2	4.70	9.40	10.09
		N_3	14.94	22.60	22.60
		N_4	0	0	5.19
		N_5	29.41	34.60	37.88
	INT	N_1	10.19	2.60	0
		N_2	5.01	10.17	10.48
		N_3	15.20	23.18	23.18
		N_4	0	0	5.61
		N_5	30.40	35.95	39.27
	COC	N_1	10.49	2.60	0
		N_2	5.39	10.94	10.79
		N_3	15.61	23.77	23.77
		N_4	0	0	6.12
		N_5	31.49	37.31	40.68
PERIOD II 1981 - 1990	ZPG	N_1	13.47	2.60	0
		N_2	8.55	17.11	13.95
		N_3	17.88	28.43	28.43
		N_4	0	0	9.44
		N_5	39.90	48.14	51.82
	INT	N_1	15.55	2.60	0
		N_2	10.25	20.96	15.87
		N_3	19.16	31.34	31.34
		N_4	0	0	11.56
		N_5	44.96	54.90	58.77
	COC	N_1	16.67	2.60	0
		N_2	11.71	23.73	17.11
		N_3	20.39	33.32	32.90
		N_4	0	0	13.09
		N_5	48.77	59.65	63.10
PERIOD III 1991 - 2000	ZPG	N_1	13.47	2.60	0
		N_2	8.55	19.11	13.95
		N_3	17.88	28.43	28.43
		N_4	0	0	9.44
		N_5	39.90	48.14	51.82
	INT	N_1	16.65	2.60	0
		N_2	11.48	23.27	17.11
		N_3	19.98	33.09	33.09
		N_4	0	0	12.75
		N_5	48.11	58.96	62.95
	COC	N_1	19.05	2.60	0
		N_2	14.33	28.66	19.72
		N_3	22.25	37.16	37.16
		N_4	0	0	15.81
		N_5	55.63	68.42	72.06

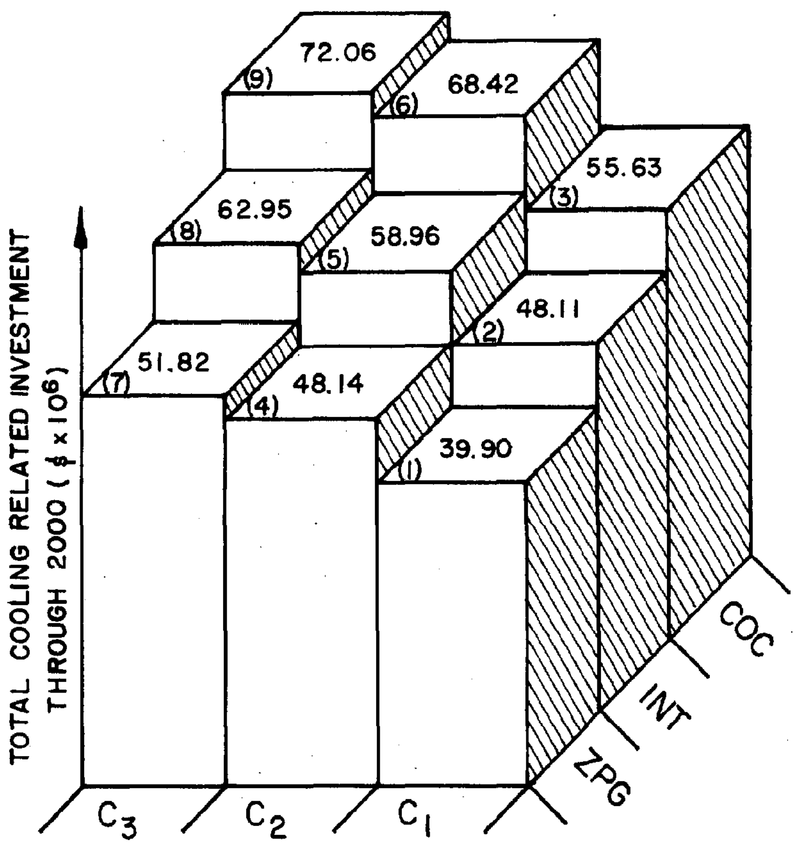
INCREASE IN INVESTMENT OVER PREVIOUS PERIOD

		C_1	C_2	C_3
PERIOD I	ZPG	12.78	16.49	16.99
	INT	13.77	17.84	18.38
	COC	14.86	19.20	19.79
PERIOD II	ZPG	10.49	13.54	13.94
	INT	14.56	18.95	19.50
	COC	17.28	22.39	22.43
PERIOD III	ZPG	0	0	0
	INT	3.15	4.06	4.18
	COC	6.86	8.77	8.96

N_1 – ONCE THROUGH
N_2 – PONDS
N_3 – WET TOWERS
N_4 – DRY TOWERS
N_5 – TOTALS

CAPITAL INVESTMENT REQUIREMENTS FOR COOLING PROCESSES, 1970 - 2000 ($-MILLIONS)
FIGURE V. 2A





TOTAL COOLING-RELATED CAPITAL INVESTMENTS
($-MILLIONS)
FIGURE V. 2B

1970

	Cell 1	Cell 4	Cell 7
ZPG	.33 0 1.25 0 1.58	.16 0 1.71 0 1.87	0 .18 1.71 0 1.80
INT	.33 0 1.25 0 1.58	.16 0 1.71 0 1.87	0 .18 1.71 0 1.89
COC	.33 0 1.25 0 1.58	.16 0 1.71 0 1.87	0 .18 1.71 0 1.89

1975

ZPG	.46 .08 1.44 0 1.98	.14 .17 2.12 0 2.43	0 .26 2.09 .86 3.21
INT	.47 .08 1.46 0 2.01	.16 .15 2.15 0 2.46	0 .26 2.12 .86 3.24
COC	.48 .10 1.46 0 2.04	.15 .17 1.99 0 2.31	0 .27 2.13 1.01 3.41

1980

ZPG	.60 .16 1.64 0 2.40	.16 .31 2.50 0 2.97	0 .33 2.50 1.69 4.52
INT	.64 .17 1.66 0 2.47	.17 .34 2.54 0 3.05	0 .35 2.54 1.76 4.65
COC	.65 .19 1.72 0 2.56	.16 .37 2.65 0 3.18	0 .37 2.65 1.85 4.87

1985

ZPG	.73 .23 1.80 0 2.76	.16 .45 2.82 0 3.43	0 .39 2.82 2.38 5.59
INT	.79 .24 1.89 0 2.92	.15 .51 3.03 0 3.69	0 .43 3.03 2.55 6.01
COC	.83 .28 2.00 0 3.11	.16 .56 3.15 0 3.87	0 .46 3.16 2.90 7.52

1990

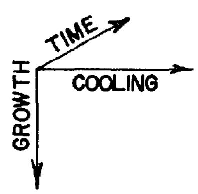
ZPG	.83 .30 1.96 0 3.09	.16 .56 3.17 0 3.89	0 .45 3.21 2.86 6.52
INT	.97 .34 2.08 0 3.39	.16 .69 3.43 0 4.28	0 .51 3.43 3.74 7.68
COC	1.03 .39 2.25 0 3.67	.15 .81 3.63 0 4.59	0 .56 3.66 4.31 8.53

1995

ZPG	.83 .30 1.96 0 3.09	.16 .56 3.17 0 3.89	0 .45 3.21 2.86 6.52
INT	1.02 .37 2.12 0 3.51	.17 .75 3.55 0 4.47	0 .56 3.55 3.89 8.00
COC	1.09 .44 2.34 0 3.87	.16 .85 3.89 0 4.90	0 .62 3.89 4.58 9.09

2000

ZPG	.83 .30 1.96 0 3.00	.16 .56 3.17 0 3.89	0 .45 3.21 2.86 6.52
INT	1.04 .38 2.17 0 3.59	.15 .79 2.63 0 4.57	0 .57 3.63 4.05 8.25
COC	1.17 .47 2.50 0 4.14	.15 .94 4.17 0 5.26	0 .66 4.09 4.91 9.66



1	4	7
2	5	8
3	6	9

CELL CODE

KEY

N_1
N_2
N_3
N_4

N_1 = ONCE THROUGH
N_2 = PONDS
N_3 = WET TOWERS
N_4 = DRY TOWERS

(KWH x 10^6)

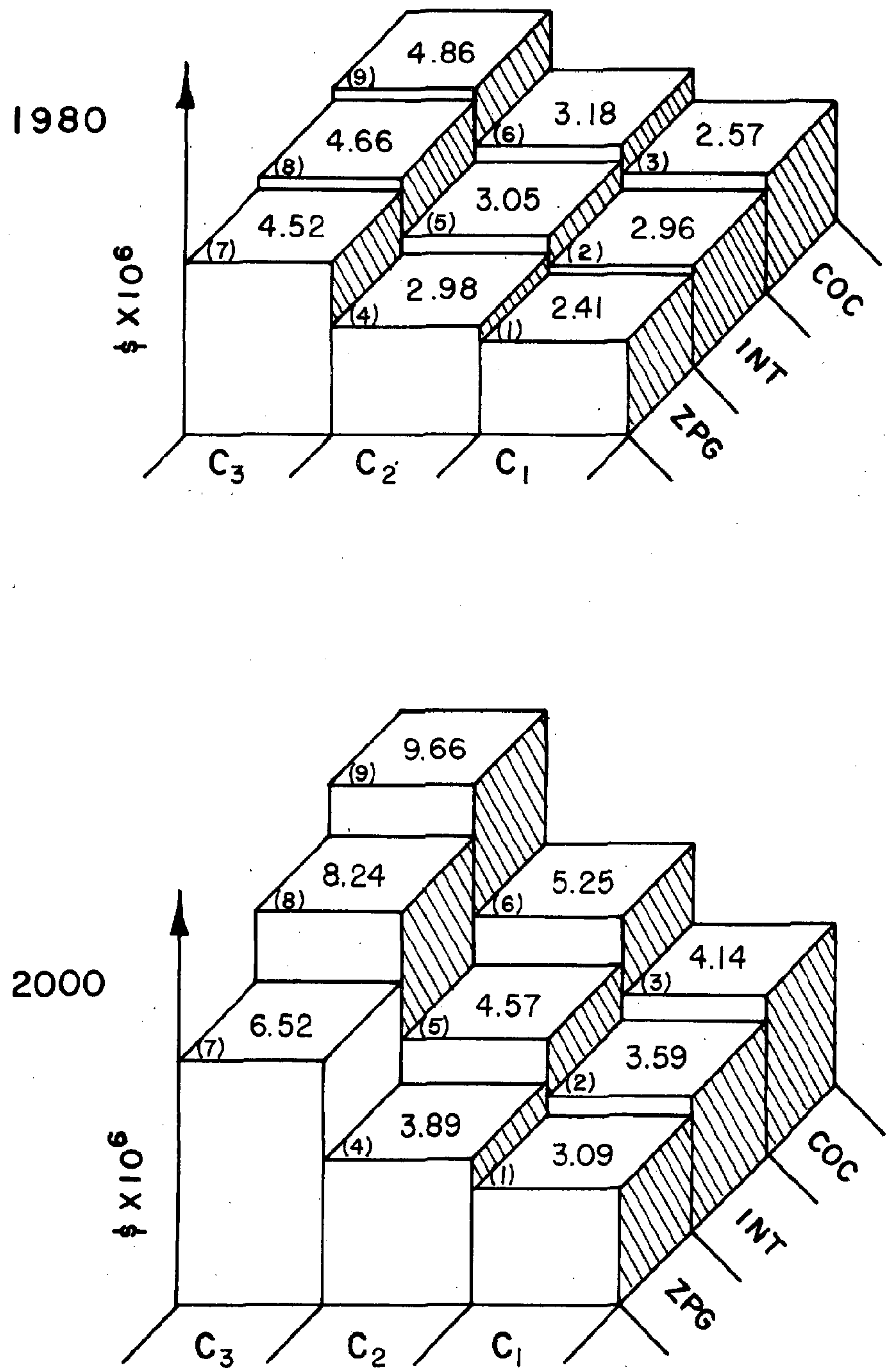
COMPONENTS OF ANNUAL PROJECTED COOLING COSTS BY PROCESS FOR EACH FUTURE ($-MILLIONS)

FIGURE V. 2C

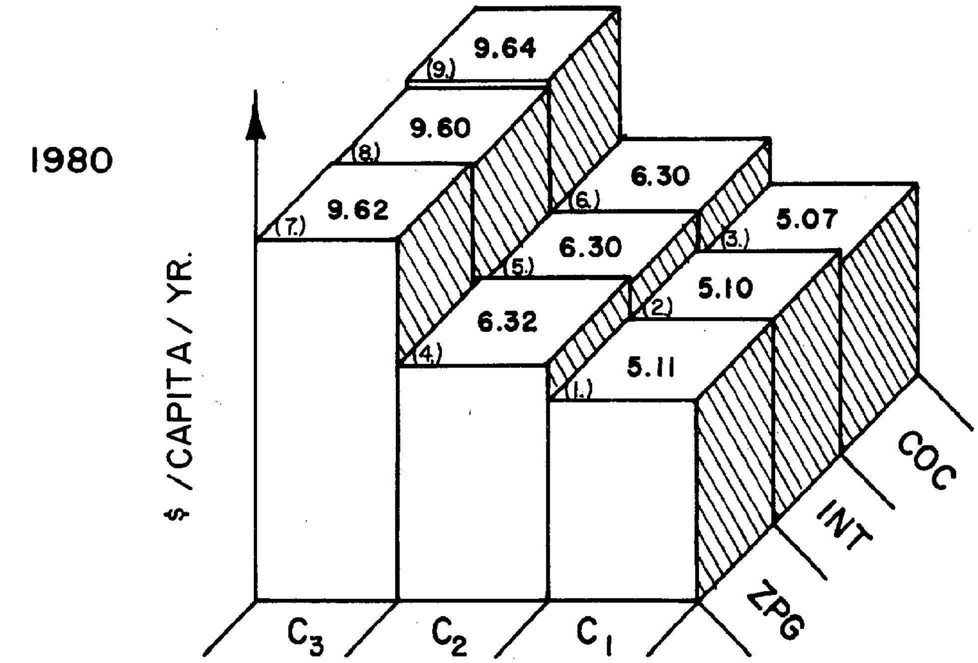
The lower part of Figure V.2B gives the total cooling related investments required to meet any of the nine alternatives through the year 2000. The total investment varies by almost a factor of two between the \$39.90 million required by Case 1 (ZPG, C_1) and the \$72.06 million required by Case 9 (COC, C_3). Further examination of Figure V.2B reveals other information such as (a) the C_3 policy requires about 30 percent more capital investment than C_1 and this holds for all growth levels, (b) for any cooling policy, the capital investment required under the COC growth policy is about 40 percent more than under the ZPG policy.

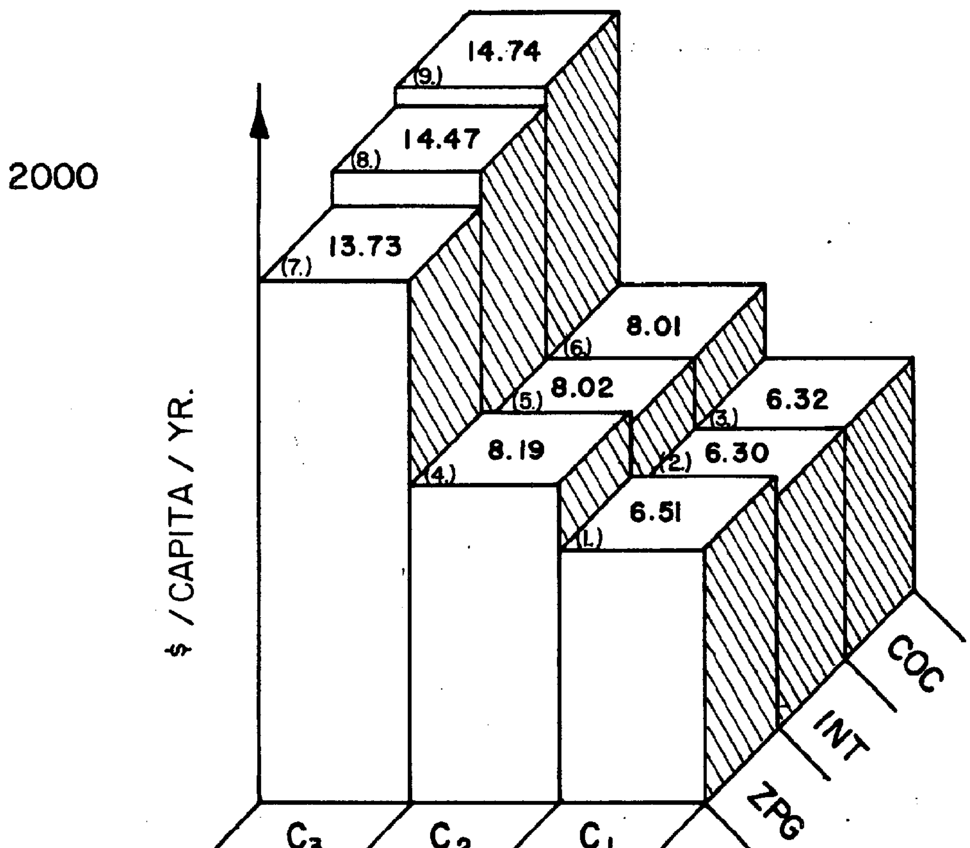
The annual costs (\$/YR) required for cooling purposes for five-year intervals from 1970 to 2000 are shown in Figure V.2C. These figures reflect capital amortization, operation, maintenance, taxes, insurance, etc. The first four figures in each cell are the annual costs attributable to each process, and the fifth figure is the sum of these costs which represents the total annual cost. These data were developed in a manner identical to those in Figure V.2A, except that annual energy production rather than installed generating capacity, was the principal variable. The annual energy production data (KWH/YR - Figure V.1B) were multiplied by the appropriate unit cost information (\$/KWH) from Figure IV.2E to derive the annual costs (\$/YR) shown in Figure V.2C.

The two 3 x 3 surfaces developed from data given in Figure V.2C presented in Figure V.2D show the annual cost, in millions of dollars, attributable to cooling processes for 1980 and 2000. For 1980 the total annual cooling cost for any given growth level almost doubles under the C_3 policy, as compared to the C_1 policy. For the year 2000 this difference ranges between 2.1 and 2.3.



TOTAL ANNUAL COOLING RELATED COSTS FOR TWO SELECT YEARS, 1980 - 2000
FIGURE V.2D





TOTAL PER CAPITA COST DUE TO COOLING ($/CAPITA/YR.)

FIGURE V. 2E

The data in Figure V.2E go a step further and give the annual average per capita cost of electricity resulting from cooling related expenditures. These costs were computed by dividing total annual cost by the estimated population. For the year 2000 these cooling-related costs range from about \$6.30 to about \$14.75 per capita. Thus, if public-policy should dictate the zero-heat discharge option, the realistic anticipated cost per person is about \$14.30 in electrical bills per year just to pay for this elimination of heat discharge. For a family of five this cost would amount to about \$72.00 per year or almost \$6.00 per month. Under the C_1 or relatively lax policy, where localized standards would be met to protect specific aquatic communities, these costs would average about \$6.40 per person, or \$32.00 per five member family per year. Therefore, if the no-discharge, C_3 policy were adopted, instead of the immediate discharge area protection alternative of policy C_1, a five member family would have to pay an average of approximately \$40.00 per year more in electrical bills. This \$40.00 per year per family is an average figure. If the family's per capita consumption were greater than the average for the region the \$40.00 figure would be too low; conversely, if their consumption were below average, the \$40.00 figure would be too high.

While these average data do not differentiate among income levels, the data shown in Figure V.2E provide a means by which the direct cost implications of the alternative policies can be simply determined. Such data are inexact, but they are better than nothing. Some of the economic implications of these cost increases will be quantified later in this chapter (V.4) by using these cost differentials to trigger changes and trace their impacts in the regional input-output model, which takes into account indirect as well as direct costs.

V. 3 NATURAL RESOURCE REQUIREMENTS FOR SATISFYING ALTERNATIVE PUBLIC POLICIES

The costs of the various cooling system alternatives will undoubtedly be a significant factor in determining how any public policy may ultimately be implemented. However, certain other considerations also will be important, and may, under certain circumstances eliminate or override the economically preferable solution. This fact is particularly applicable to some natural resource requirements which may themselves become limiting factors in the selection and operation of waste heat disposal systems.

Natural resources which might become limiting factors are water, land and energy (i.e., fuel). In assessing whether or not any natural resource considerations might impose limits on the selection of a waste heat disposal system, it is necessary to consider availability, reliability, competing uses, costs, and possible changing public attitudes toward the use of a given natural resource.

Consumptive Uses of Water

Water is the most obvious natural resource affected by power plant cooling. In evaluating water use and its implications, a careful distinction must be made between water throughput and water consumption, which were discussed at length in Section IV.2. Based upon the unit water use data (both throughput and consumption) given in Table IV.2G, and the annual electrical energy production shown in Figure V.1B, water throughput and water consumption could be computed for the nine alternative futures.

Consumptive water use estimates at five-year intervals for the period 1970 - 2000 are presented in Figure V.3A. A three-dimensional plot of the same data for the years 1980 and 2000 is shown in Figure V.3B. The

1970

	C_1	C_2	C_3
ZPG	430 / 0 / 1770 / 0 / 2200	150 / 0 / 2420 / 0 / 2570	0 / 150 / 2420 / 0 / 2570
INT	430 / 0 / 1770 / 0 / 2200	150 / 0 / 2420 / 0 / 2570	0 / 150 / 2420 / 0 / 2570
COC	430 / 0 / 1770 / 0 / 2200	150 / 0 / 2420 / 0 / 2570	0 / 150 / 2420 / 0 / 2570

1975

ZPG	610 / 100 / 2040 / 0 / 2750	180 / 210 / 3000 / 0 / 3390	0 / 300 / 2960 / 0 / 3260
INT	620 / 100 / 2070 / 0 / 2790	210 / 180 / 3040 / 0 / 3430	0 / 310 / 3000 / 0 / 3310
COC	630 / 120 / 2060 / 0 / 2810	200 / 200 / 2830 / 0 / 3230	0 / 320 / 3000 / 0 / 3320

1980

ZPG	800 / 190 / 2330 / 0 / 3320	210 / 390 / 3200 / 0 / 3780	0 / 390 / 3200 / 0 / 3590
INT	840 / 200 / 2350 / 0 / 3390	220 / 400 / 3600 / 0 / 4220	0 / 420 / 3600 / 0 / 4020
COC	860 / 230 / 2440 / 0 / 3530	210 / 440 / 3750 / 0 / 4400	0 / 440 / 3750 / 0 / 4190

1985

ZPG	960 / 270 / 2550 / 0 / 3780	210 / 540 / 3990 / 0 / 4740	0 / 480 / 3990 / 0 / 4470
INT	1050 / 290 / 2670 / 0 / 4010	200 / 600 / 4280 / 0 / 5080	0 / 510 / 4280 / 0 / 4780
COC	1090 / 330 / 2840 / 0 / 4260	210 / 660 / 4470 / 0 / 5340	0 / 540 / 4470 / 0 / 5010

1990

ZPG	1090 / 360 / 2780 / 0 / 4230	210 / 670 / 4490 / 0 / 5370	0 / 540 / 4540 / 0 / 5080
INT	1280 / 400 / 2940 / 0 / 4790	210 / 820 / 4860 / 0 / 6140	0 / 610 / 4860 / 0 / 5700
COC	1360 / 460 / 3190 / 0 / 5030	200 / 970 / 5140 / 0 / 6310	0 / 660 / 5180 / 0 / 5840

1995

ZPG	1090 / 360 / 2780 / 0 / 4230	210 / 670 / 4490 / 0 / 5370	0 / 540 / 4540 / 0 / 5080
INT	1340 / 450 / 3000 / 0 / 4790	220 / 890 / 5030 / 0 / 6140	0 / 670 / 5030 / 0 / 5700
COC	1440 / 520 / 3310 / 0 / 5270	220 / 1010 / 5510 / 0 / 6740	0 / 740 / 5410 / 0 / 6160

2000

ZPG	1090 / 360 / 2780 / 0 / 4230	210 / 670 / 4490 / 0 / 5370	0 / 540 / 4540 / 0 / 5080
INT	1370 / 460 / 3080 / 0 / 4910	200 / 940 / 5130 / 0 / 6270	0 / 680 / 5130 / 0 / 5810
COC	1540 / 560 / 3540 / 0 / 56.40	200 / 1110 / 5900 / 0 / 7210	0 / 790 / 5800 / 0 / 6590

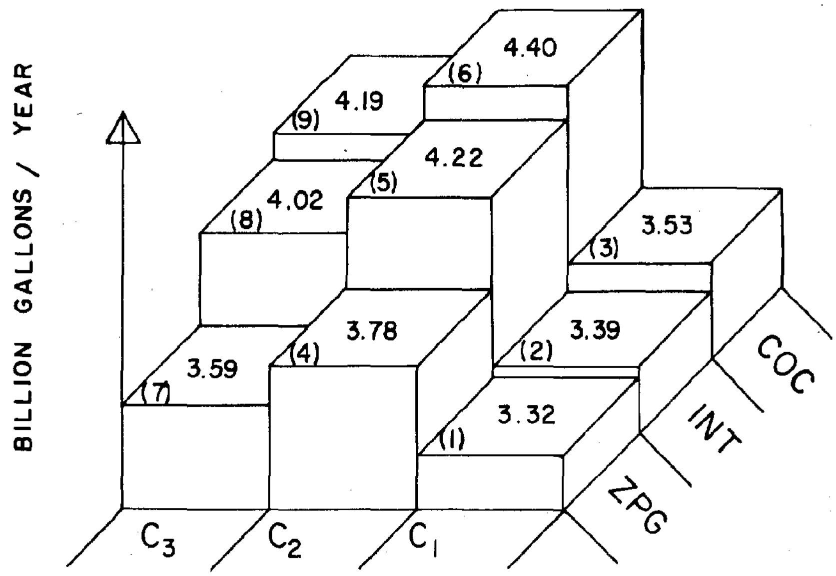
KEY

N_1
N_2
N_3
N_4
N_5
CELL LJ

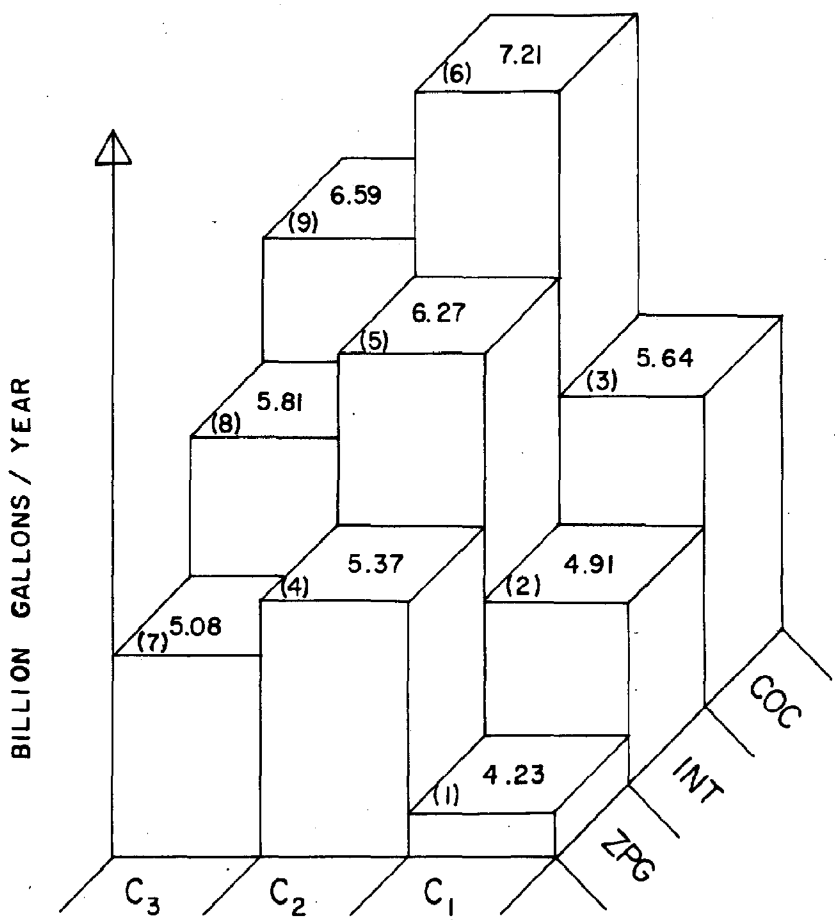
N_1 = ONCE THROUGH
N_2 = PONDS
N_3 = WET TOWERS
N_4 = DRY TOWERS
N_5 = TOTAL

CONSUMPTIVE WATER USE (MILLION GALLONS/YEAR)
FIGURE V. 3A

1980



2000



ANNUAL CONSUMPTIVE WATER USE FOR YEARS 1980 AND 2000 (BILLION GALS./YR.)
FIGURE V. 3B

relative implications of growth and cooling policies on water consumption are clearly illustrated by this three-dimensional diagram. For the year 1980 the values vary from 3.32 to 4.40 billion gallons per year depending on the alternative future being considered. It can be seen that for the year 1980, changes in the cooling policy have a significantly greater impact than those in growth levels, i.e , consumptive use is more sensitive to cooling policy than to growth policy (27 percent vs. 17 percent).

The estimated consumptive use for the year 2000 shows a greater difference between alternative growth policies than do the 1980 data. The maximum difference occurs between growth policies (35 percent) rather than between cooling policies where the maximum difference is the same as in 1980, namely, 27 percent. This fact should not be surprising since the analysis is structured to subject all growth policies to the same cooling policy, whereas the population growth projections begin to diverge significantly beyond 1985 when the ZPG projection becomes static at 475,000.

The policy C_2 in Figure V.3B indicates that the "Constant BTU" approach requires more water than C_3 or "zero discharge" policy because policy C_3 uses some dry towers, whereas C_2 relies principally on wet towers and ponds which evaporate approximately 0.75 and 0.27 gallons/KWH of electricity produced, respectively.

These data in billions of gallons per year may seem rather meaningless, and therefore some examples are given to relate these to other uses. The maximum use figure of 7.21 billion gallons per year equals 19.8 million gallons per day, or 22,130 acre-feet or 30.63 cubic feet per second.

The COC population projection, from which the 7.21 billion gallons per year is developed, shows an estimated population of 655,000 in the year

2000. Therefore, this level of water use is equivalent to 30.2 gallons per capita per day which compares with a national household average total use of about 150 gallons per capita per day. However, only a small fraction, about 45 to 60 gallons of this daily volume is actually consumed. The remainder is wastewater and is eventually discharged.

The significance of these differences in water consumption of 6.6 gallons per capita per day (23.6 for C_1, 30.2 for C_2) may be questioned. However, under certain circumstances this water consumption could become quite critical, e.g., in arid or semi-arid areas where fresh water might be a limiting factor on additional growth or other water uses, including stream flow maintenance or fresh water inflows to estuaries.

On a national basis with a population of 300 million, this consumptive use could amount to 720 billion gallons per year, or 2.2 million acre-feet per year. For comparative purposes, the annual firm yield of the entire Trinity River Basin, if fully developed, is 2.30 million acre-feet (Texas Water Plan, 1968). The total water consumed nationally under the stricter policy would amount to 3,290 billion gallons per year or 10.1 million acre-feet per year, or 13,900 cubic-feet per second. The average flow of the Mississippi River at New Orleans is 900,000 cubic-feet per second (U.S. Geological Survey, 1971).

Although many comparisons illustrating the amount of freshwater involved could be made, such numerical exercises are largely meaningless, until some specific alternative is proposed or some measure of benefit delineated for consumptively using this water in the electrical generation process. What is salient is that sizable quantities of fresh water, especially for a water-short, arid region, are required for electrical power generation.

Water Throughput

Figures V.3C and V.3D address another water-related question, that of total water throughput, i.e., the amount of water moved across the condensers. The throughput water is affected only by an increase in temperature. For any given size plant, throughput volume is an inverse function of temperature rise across condensers. About 40 gallons of water per KWH generated are required for a 14-15^{o} F rise, which is a common practice for electrical generating plants in Texas coastal areas. Of each 40 gallons only a small fraction is evaporated, namely 1.88 percent (0.75 gallons/KWH) for evaporative towers and 0.68 percent (0.27 gallons/KWH) for ponds. Current technology restricts evaporative towers to fresh water because of salt spray drift, however either fresh or salt water can be used with cooling ponds, although the buildup of total dissolved solids eliminates continuous recycling of salt water through a pond system.

The data in Figure V.3D indicate that policies C_1 and C_2 require more water throughput than policy C_3, because C_1 and C_2 rely on various mixes of once-through, ponds and towers. However, while the consumptive losses differ, the same volume of water must be moved across the condensers for both C_1 and C_2. C_3 uses some dry cooling towers so the throughput is lower.

Changes in growth policy have substantially more effect on water throughput than do changes in cooling policy. For the maximum growth case, COC, this water throughput is about half a trillion (524 billion) gallons per year. Expressed in other units 1.6 million acre-feet per year or 2220 cubic-feet per second are required. This water throughput is equivalent to passing the total volume of Lake Corpus Christi (302 thousand acre-feet) through a plant 5.3 times per year or about once every two months. For a body of water the size of Corpus Christi Bay, with an estimated volume of 1382 million

1970

	C	C	C
ZPG	68.8 0 94.4 0 163.2	34.0 0 129.2 0 163.2	0 34.4 128.8 0 163.2
INT	68.8 0 94.4 0 163.2	34.0 0 129.2 0 163.2	0 34.4 128.8 0 163.2
COC	68.8 94.4 0 0 163.2	34.0 0 129.2 0 163.2	0 34.4 128.8 0 163.2

1975

97.6 15.6 108.8 0 222.0	28.8 33.2 160.0 0 222.2	0 48.8 157.6 0 206.4
99.2 15.6 110.4 0 225.2	34.0 29.2 162.0 0 225.2	0 49.6 160.0 0 209.4
100.8 18.4 110.0 0 229.2	34.0 34.0 161.2 0 229.2	0 50.4 160.4 0 210.8

1980

127.2 30.8 124.0 0 282.0	34.0 59.2 188.8 0 282.0	0 62.4 188.8 0 251.2
133.6 32.0 125.2 0 290.8	34.8 64.0 192.0 0 290.8	0 66.8 192.0 0 258.8
136.8 36.4 130.0 0 303.2	33.2 70.0 200.0 0 303.2	0 69.6 200.0 0 269.6

1985

153.2 43.2 136.0 0 332.4	34.0 85.6 212.8 0 332.4	0 76.0 213.2 0 289.2
168.0 46.4 142.4 0 356.8	32.0 96.4 228.4 0 356.8	0 82.0 228.4 0 310.4
174.0 52.8 151.2 0 378.0	34.0 100.0 238.0 0 378.0	0 88.8 238.4 0 325.2

1990

174.8 57.2 148.0 0 380.0	34.0 106.8 239.2 0 380.0	0 86.0 242.0 0 328.0
204.0 64.0 156.8 0 424.8	34.0 131.6 259.2 0 424.8	0 97.6 259.2 0 356.8
216.8 74.0 170.0 0 460.8	32.4 154.4 274.0 0 460.8	0 106.0 276.4 0 382.4

1995

174.8 57.2 148.0 0 380.0	34.0 106.8 239.2 0 380.0	0 86.0 242.0 0 328.0
214.4 71.2 160.0 0 445.6	34.8 142.8 268.0 0 445.6	0 106.8 268.0 0 374.8
230.0 83.2 176.4 0 489.6	34.4 161.6 293.6 0 489.6	0 117.6 288.8 0 406.4

2000

174.8 57.2 148.0 0 380.0	34.0 106.8 239.2 0 380.0	0 86.0 242.0 0 328.0
218.8 73.2 164.0 0 456.0	32.0 150.4 273.6 0 456.0	0 108.8 273.6 0 382.4
246.0 89.2 188.8 0 524.0	31.6 178.0 314.4 0 524.0	0 125.6 309.2 0 434.8

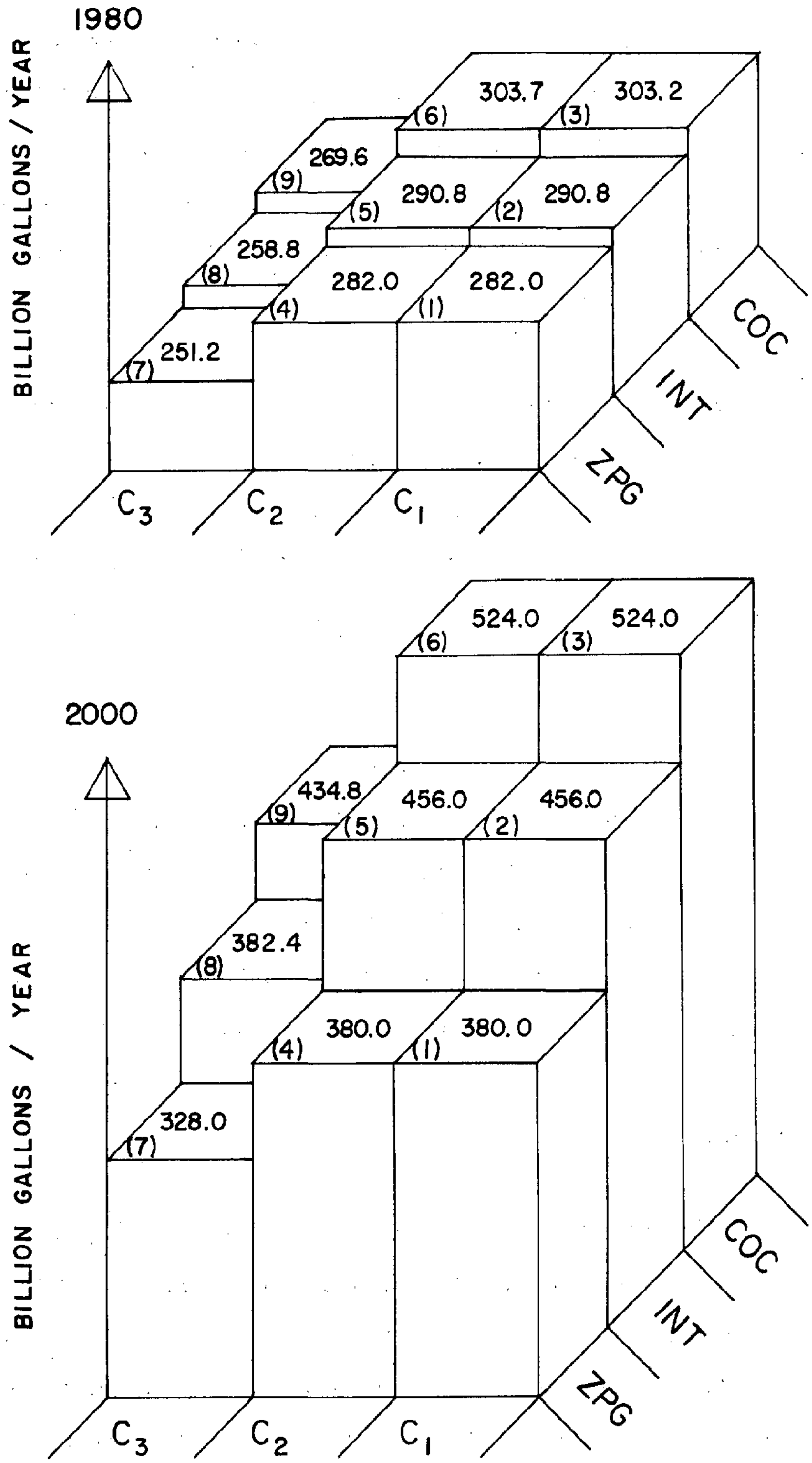
KEY

N_1 N_2 N_3 N_4 N_5

CELL LJ

N_1=ONCE THROUGH
N_2=PONDS
N_3=WET TOWERS
N_4=DRY TOWERS
N_5=TOTAL

TOTAL WATER THROUGH PUT (BILLION GALLONS/YEAR)
FIGURE V. 3C



ANNUAL WATER THROUGHPUT FOR 1980 AND 2000
BILLION GALLONS PER YEAR
FIGURE V.3D

acre-feet, this recirculation interval would be a year. Complete mixing in any body of waters such as a reservoir or estuary is never practical, therefore some of the volume is recirculated more frequently and some less frequently. A number of natural processes, such as inflows to and releases from a reservoir, precipitation, evaporation, tidal action and the physical arrangement of inlets, discharges, and baffles, all greatly affect circulation patterns and the recirculation method.

Meaningful assessment of water throughput is most speculative for general cases on a regional basis. To deduce any meaningful information from such numbers it is necessary to identify a specific plant site and a specific receiving water body. Even then there will be considerable differences of opinion over the ecological impact of such water circulation, apart from temperature considerations.

Nevertheless, almost inconceivably large amounts of water are involved. If the entire U.S. adopted a policy similar to either C_1 or C_2 then more than 238,000 billion gallons per year would have to go through power plants at an average rate of 1,010,000 cubic-feet per second. The utilization of such amounts of water for cooling purposes would certainly have a significant effect on the future water resource picture in this country.

Land Requirements

The significance of the land requirement in selecting a cooling process is underplayed, but in many instances availability and/or cost of the real estate may preclude the use of certain cooling methods. The importance of the land requirement is increased by the fact that power plants often are located adjacent to a body of surface water where competing uses and land values are the highest.

The space required for generating facilities, fuel storage, switching equipment, and service areas is essentially independent of the cooling method used. The estimated resource requirements, including unit land requirements, for different cooling techniques were presented in Table IV.2G. Simple once-through cooling requires no large land areas, while cooling ponds require the most land area. For heat rejection rates of 7000 BTU/hour (32 percent efficiency) of installed capacity, pond surface area should be about 1.5 acres/MW.

Evaporative towers require, as a minimum, about 0.5 acres/MW. However, the mist drift may produce problems and necessitate significant buffer areas adjacent to the towers. This land is in addition to the areas actually required for the towers themselves. Dry towers require more space, with something on the order of 0.8 acres/MW being required to prevent inflow interference between tower inlet streams.

When the land requirements given in Table IV.2G are applied to the distribution of cooling techniques presented in Section V.1, the total land requirements for the nine combinations of growth and environmental policies can be computed. These requirements are shown in Figure V.3E for the 1970-2000 period. A three-dimensional plot of these data for 1980 and 2000 are presented in Figure V.3F.

The implication of these data is that cooling policy has a greater impact on land requirements than does growth policy, although both are significant. In 1980 the C_3 policy requires more real estate than does C_2 for all growth policies. By the year 2000 the situation is changed: the INT policy requires the same land area (3690 acres) for both C_1 and C_2, whereas for the ZPG policy less land is required, while in the year 2000 more land is needed for the C_2 policy than for the C_3 policy. The C_2 policy relies more

KEY (CELL LJ)

N_1
N_2
N_3
N_4
N_5

N_1 = ONCE THROUGH
N_2 = PONDS
N_3 = WET TOWERS
N_4 = DRY TOWERS
N_5 = TOTAL

1970

	C_1	C_2	C_3
ZPG	0 / 0 / 490 / 0 / 490	0 / 0 / 665 / 0 / 665	0 / 525 / 665 / 0 / 1190
INT	0 / 0 / 490 / 0 / 490	0 / 0 / 665 / 0 / 665	0 / 525 / 665 / 0 / 1190
COC	0 / 0 / 490 / 0 / 490	0 / 0 / 665 / 0 / 665	0 / 525 / 665 / 0 / 1190

1975

	C_1	C_2	C_3
ZPG	0 / 233 / 568 / 0 / 801	0 / 465 / 820 / 0 / 1285	0 / 758 / 820 / 124 / 1702
INT	0 / 233 / 568 / 0 / 801	0 / 465 / 820 / 0 / 1285	0 / 765 / 820 / 128 / 1713
COC	0 / 833 / 768 / 0 / 1601	0 / 1665 / 1220 / 0 / 2885	0 / 1358 / 1220 / 444 / 3022

1980

	C_1	C_2	C_3
ZPG	0 / 458 / 643 / 0 / 1101	0 / 915 / 970 / 0 / 1885	0 / 983 / 970 / 244 / 2197
INT	0 / 488 / 653 / 0 / 1141	0 / 990 / 995 / 0 / 1985	0 / 1020 / 995 / 264 / 2279
COC	0 / 525 / 670 / 0 / 1195	0 / 1065 / 1020 / 0 / 2085	0 / 1050 / 1020 / 288 / 2358

1985

	C_1	C_2	C_3
ZPG	0 / 668 / 713 / 0 / 1381	0 / 1335 / 1105 / 0 / 2440	0 / 1193 / 1105 / 356 / 2654
INT	0 / 743 / 738 / 0 / 1481	0 / 1515 / 1170 / 0 / 2685	0 / 1290 / 1170 / 400 / 2860
COC	0 / 825 / 770 / 0 / 1595	0 / 1665 / 1220 / 0 / 2885	0 / 1350 / 1220 / 448 / 3018

1990

	C_1	C_2	C_3
ZPG	0 / 833 / 768 / 0 / 1601	0 / 1665 / 1220 / 0 / 2885	0 / 1358 / 1220 / 444 / 3022
INT	0 / 998 / 823 / 0 / 1821	0 / 2040 / 1345 / 0 / 3385	0 / 1545 / 1345 / 544 / 3434
COC	0 / 1140 / 875 / 0 / 2015	0 / 2310 / 1430 / 0 / 3740	0 / 1665 / 1410 / 610 / 3691

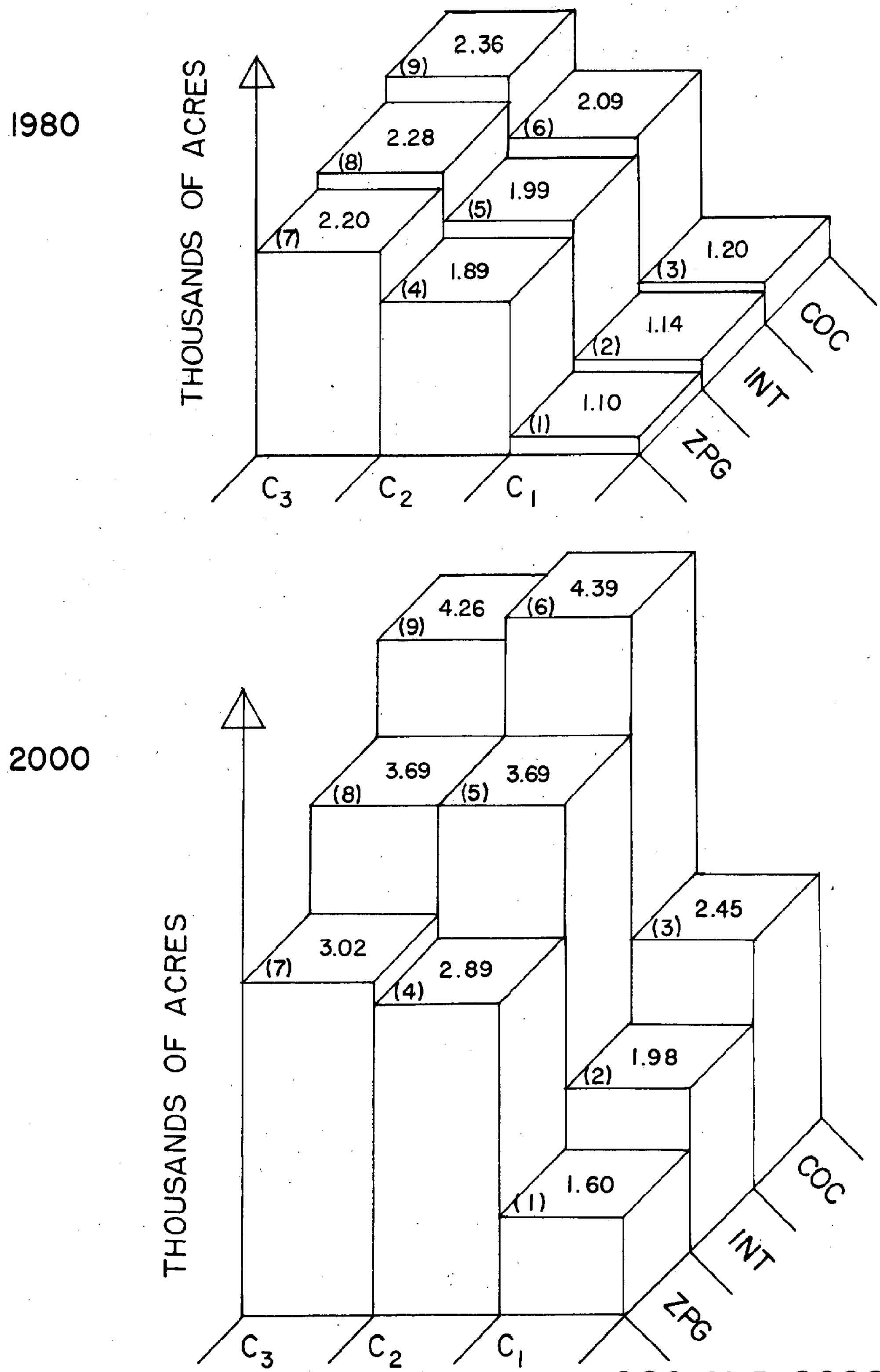
1995

	C_1	C_2	C_3
ZPG	0 / 833 / 768 / 0 / 1601	0 / 1665 / 1220 / 0 / 2885	0 / 1358 / 1220 / 444 / 3022
INT	0 / 1073 / 848 / 0 / 1921	0 / 2190 / 1395 / 0 / 3585	0 / 1620 / 1395 / 584 / 3599
COC	0 / 1260 / 920 / 0 / 2180	0 / 2535 / 1505 / 0 / 4040	0 / 1785 / 1510 / 544 / 3967

2000

	C_1	C_2	C_3
ZPG	0 / 833 / 768 / 0 / 1601	0 / 1665 / 1220 / 0 / 2885	0 / 1358 / 1220 / 444 / 3022
INT	0 / 1118 / 858 / 0 / 1976	0 / 2265 / 1420 / 0 / 3685	0 / 1665 / 1420 / 600 / 3685
COC	0 / 1395 / 955 / 0 / 2450	0 / 2790 / 1595 / 0 / 4385	0 / 1920 / 1595 / 744 / 4259

LAND REQUIREMENT (ACRES)
FIGURE V. 3E



LAND AREA REQUIRED IN 1980 AND 2000
THOUSANDS OF ACRES
FIGURE V. 3F

heavily on cooling ponds which require substantially more land than do either wet or dry towers. As expected, the C_1 policy, which relies heavily on once-through cooling, requires the least land of all the policies being considered.

It can be safely said that the projected land requirements, ranging from 1600 - 4390 acres for the various policies, will not constitute a significant problem in the South Texas study area. Furthermore, because of the abundance of potentially usable, relatively inexpensive property, land should not be an overriding factor in site selection. However, substantial cost must be anticipated because of the requirement of location in high value, waterfront areas. In other areas of the country, such as the northeast or southern Pacific coast, the costs of waterfront real estate, which will go into the millions of dollars per acre, could become prohibitive.

One solution would be to develop such valuable real estate for multipurpose uses in addition to cooling facilities. Ponds which can be used for limited recreational purposes offer the only feasible opportunity. The potential of ponds to support and/or enhance aquaculture operations also is being explored at several sites.

Energy Requirements

Before the current energy shortage no concern about the power requirements of the different cooling techniques was expressed. If one raised this issue, the standard comment was invariable: "Why should this be a problem, after all power plants generate power, so just make the plant a little bigger to allow for the cooling requirement."

Now, even though the energy consumption differential between two cooling methods might be only a few percent of the output, even these small amounts have become significant, especially in the warmer areas of the U.S. where the peak energy demand is caused by air conditioning, and coincides with the highest natural exhaust temperatures which in turn result in the least efficient cooling system operation.

The annual energy requirements (KWH/YR) for the nine alternative five-year steps for 1970-2000 are shown in Figure V.3G. These requirements were derived from the unit energy requirements developed in Table IV.2G and the allocation of generation capacity among cooling processes presented in Section V.1. Unit energy requirements vary by about a factor of 10, ranging from 1.33 KWH/1000 KWH for once-through cooling to 16.00 KWH/1000 KWH for dry mechanical draft towers.

A three-dimensional plot of the energy requirements for the alternative for the years 1980 and 2000 is illustrated in Figure V.3H. These data are given in KWH/1000 KWH; thus, dividing the numbers shown in Figure V.3H by 10 gives the percent of the total electrical output which will have to be devoted to operating the cooling system.

For 1980, the data in Figure V.3H indicate that the C_2 requires only 18-25 percent more energy than the C_1 policy. The reason for this increase is apparent since C_2 relies heavily on wet towers, which require about three times the energy of once-through systems or ponds, while C_1 relies mostly on the latter two processes. The C_3 energy requirement is very high, because dry tower cooling which is a very energy-intensive cooling process is included. In 1980 there is relatively little difference between the percentages of energy usage for the various growth policies, because even for C_3 the percentage of tower capacity (and especially dry tower capacity) as compared to ponds, has not grown and become as significant as twenty years hence.

1970

	C_1	C_2	C_3
ZPG	2.3 0 9.4 0 11.7	1.1 0 12.9 0 14.0	0 1.3 12.9 0 14.2
INT	2.3 0 9.4 0 11.7	1.1 0 12.9 0 14.0	0 1.3 12.9 0 14.2
COC	2.3 0 9.4 0 11.7	1.1 0 12.9 0 14.0	0 1.3 12.9 0 14.2

1975

ZPG	3.2 .6 10.9 0 14.7	1.0 1.2 16.0 0 18.2	0 1.8 15.8 6.3 13.9
INT	3.3 .6 11.0 0 14.9	1.1 1.1 16.2 0 18.4	0 1.9 16.0 6.3 14.2
COC	3.4 .7 11.0 0 15.1	1.1 1.2 15.1 0 18.4	0 1.9 16.0 7.4 15.3

1980

ZPG	4.3 1.2 12.4 0 17.9	1.1 2.2 18.9 0 21.2	0 2.3 18.9 12.3 33.5
INT	4.4 1.2 12.5 0 18.1	1.2 2.4 19.2 0 22.8	0 2.5 19.2 12.8 34.5
COC	4.5 1.4 13.0 0 18.9	1.1 2.6 20.0 0 23.7	0 2.6 20.0 13.4 36.0

1985

ZPG	5.1 1.6 13.6 0 20.3	1.1 3.2 21.3 0 25.6	0 2.9 21.3 17.3 41.5
INT	5.6 1.7 14.2 0 21.5	1.1 3.6 22.8 0 27.5	0 3.1 22.8 18.6 44.5
COC	5.8 2.0 15.1 0 22.9	1.1 4.0 23.8 0 28.9	0 3.3 23.8 21.1 48.2

1990

ZPG	5.8 2.1 14.8 0 22.7	1.1 4.0 23.9 0 29.0	0 3.2 24.2 20.8 48.2
INT	6.8 2.4 15.7 0 24.9	1.1 4.9 25.9 0 31.9	0 3.7 25.9 27.7 56.8
COC	7.2 2.8 17.0 0 27.0	1.1 5.8 27.4 0 34.3	0 4.0 27.4 31.4 52.8

1995

ZPG	5.8 2.1 14.8 0 22.7	1.1 4.0 23.9 0 29.0	0 3.2 24.2 20.8 48.2
INT	7.1 2.7 16.0 0 25.8	1.2 5.4 26.8 0 33.4	0 4.0 26.8 28.3 59.1
COC	7.6 3.1 17.6 0 28.3	1.1 6.1 29.4 0 36.6	0 4.4 28.9 33.3 66.6

2000

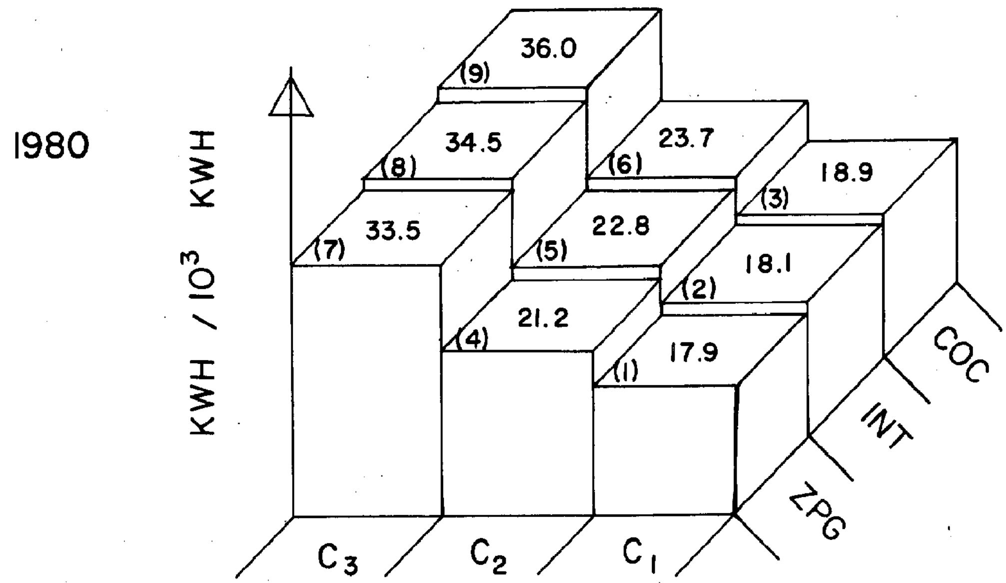
ZPG	5.8 2.1 14.8 0 22.7	1.1 4.0 23.9 0 29.0	0 3.2 24.2 20.8 48.2
INT	7.3 2.7 16.4 0 25.8	1.1 5.6 27.4 0 33.4	0 4.1 27.4 29.4 59.1
COC	8.2 3.3 18.9 0 30.4	1.0 6.7 31.4 0 39.1	0 4.7 30.9 35.7 71.3

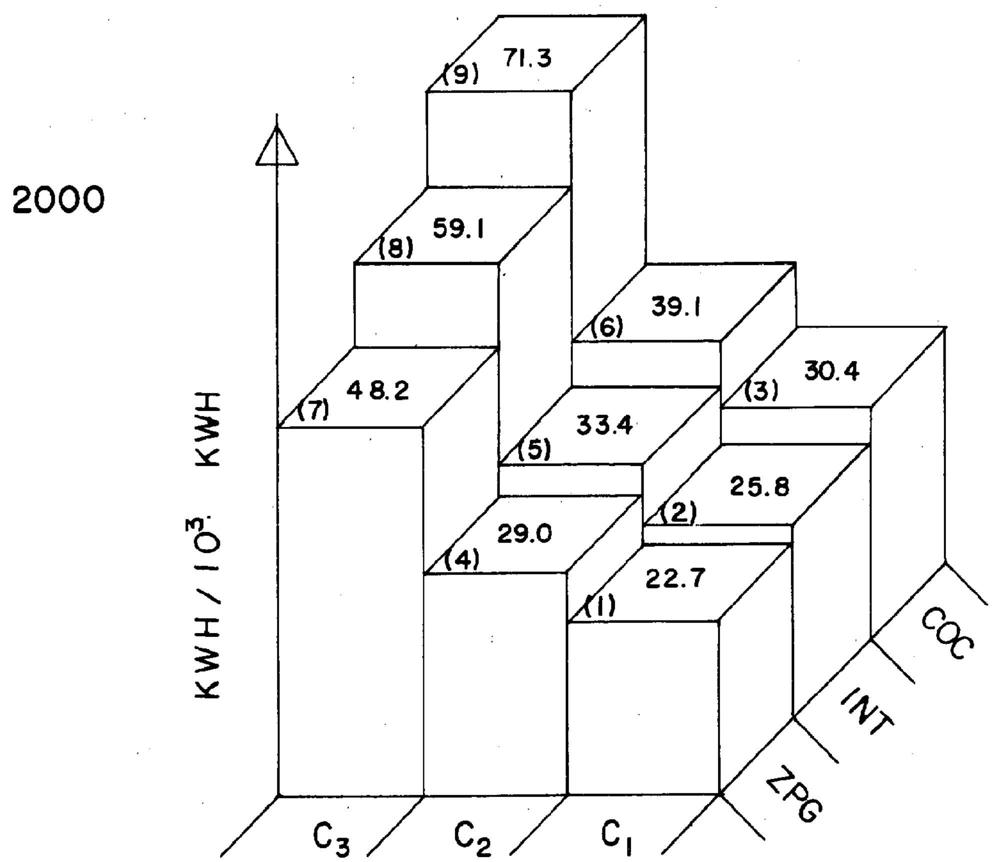
KEY

N_1 N_2 N_3 N_4 N_5
CELL LJ

N_1 = ONCE THROUGH
N_2 = PONDS
N_3 = WET TOWERS
N_4 = DRY TOWERS
N_5 = TOTAL

ANNUAL ENERGY REQUIREMENTS FOR COOLING PROCESSES
(MILLIONS OF KWH/YR.)
FIGURE V.3G





ENERGY REQUIREMENTS FOR COOLING IN 1980 & 2000 KWH REQD. /10^3 KWH PRODUCED
FIGURE V. 3H

The lower diagram in Figure V.3H shows the energy requirement for the year 2000. Depending on the policy, this requirement can range from 2.3 to 7.1 percent of total plant capacity. The C_3 policy requires from 2.1-2.3 times as much energy as the C_1 policy. Variability in energy requirements is greater than in the 1980 case because at this later date more generating capacity is needed. As more capacity is added, the percentages of cooling towers as compared to other cooling processes increases, because more added capacity goes to towers.

While it is not possible to draw specific conclusions about either the environmental or economic impact of devoting a significant portion (5-7 percent) of the total electric energy generated to driving cooling processes, some observations are possible. One of the most obvious considerations is the overall impact of this energy use on fuel supply. The total fuel requirements will be 5-7 percent more, as will the costs and all facilities, including fuel supply, generating and cooling facilities will be increased by a similar percentage. Some of the possible environmental implications are less apparent. For example, if lignite is the fuel, then, 5-7 percent more land must be strip-mined to meet the same demand; similar ratios hold for air emmissions and radiation

Observations Concerning Natural Resourses Requirements

The natural resource-related implications of the various growth and cooling policies can be summarized as follows:

(1) While dollar costs, along with regulatory practices, are likely to continue to be dominating factors in cooling process selection, the importance of natural resource availability will increase. In certain cases, constraints imposed by natural resources will determine the cooling process, or at least eliminate some cooling options.

(2) Water availability is still generally the principal natural resource consideration in the location of a power plant, and with current and intermediate range technology, water will probably continue to be the single dominant factor. For this South Texas study area, water use varies as follows, depending on the combination of policies being considered:

- Consumptive Use: 11.6 - 19.8 MGD by 2000
- Throughput: 898 - 1436 MGD by 2000

(3) Land is certainly a consideration since 1600-4400 acres will be required for cooling purposes by the year 2000. However, even though land costs may be significant, land should not become a limiting factor in the region under study, although land availability may be limited elsewhere in the U.S.

(4) Energy consumption has not been important in the past, but will become increasingly more important as a cost item and ultimately as a limiting factor. Such action will become especially important as more sophisticated cooling systems, many of which require a substantial fraction of the total plant output, are installed. The energy required to drive the cooling systems could amount to 5-7 percent of the total plant output for the gradual phasing in of mixed cooling systems. For a plant using only dry cooling towers this could run as high as 25 percent of the plant's entire output.

V.4 REGIONAL ECONOMIC IMPACT

Assessment of the economic impact of a price increase in any product is never as exact as the engineering design calculations and cost computations describing the extent and the factors affecting such prices. This inaccuracy is attributable to various factors including: (a) the lower precision of the quantitative description of the inter-relationships of the economy, (b) the complexity of the total system which must be considered, and (c) the difficulty in predicting human reactions to such changes, especially if similar changes have never been experienced. When electrical energy is the price variable this human reaction becomes particularly difficult to predict since significant price increases in this commodity have never before occurred in the U.S. and thus there is no substantial body of reliable data on customer reaction to price increases.

Despite the above difficulties, some assessment of the economic impact of cost increases due to stringent environmental control policies is a very necessary part of this investigation Thus, a procedure was developed around the Texas Input-Output Model. Input-Output Analysis is an awesome, and flexible economic analysis technique. The inventor of this technique, Wassily Leontif, was awarded the 1973 Nobel Prize in Economics almost 40 years after its development. Input-Output modeling is thoroughly discussed elsewhere (Miernyk, 1965; Cameron, 1968; Leontif, 1953; Grubb, 1971; and others) and will not be presented herein.

Input-Output Impact Analysis Procedure

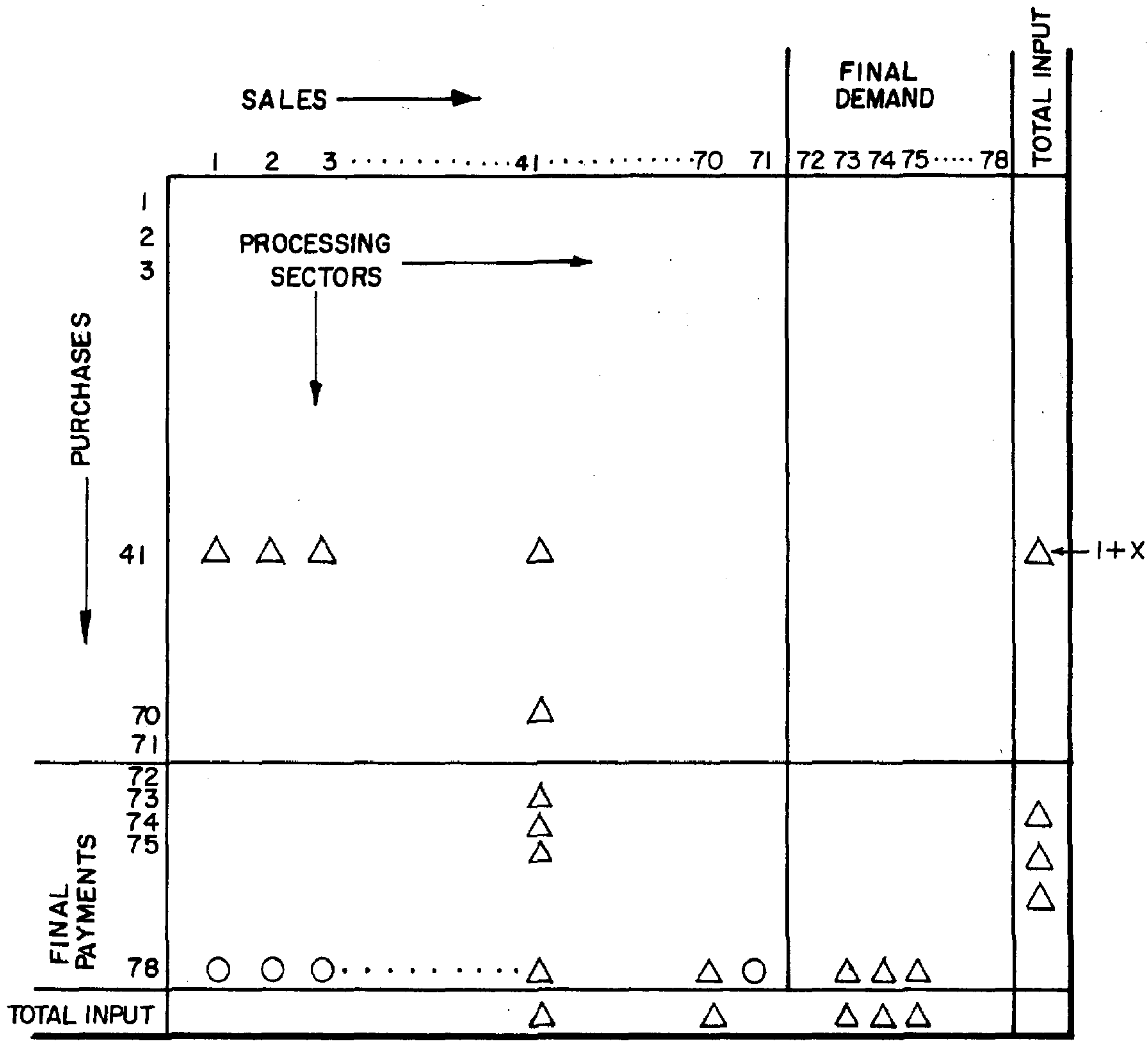
The "Texas Input-Output Project", also known as the "Texas Inter-industry Project," was initiated in 1968 in the Office of the Governor with the backing of a consortium of state agencies and with the partial financial support of the Department of Housing and Urban Development (Grubb, 1971). The initial project required three years, cost $1.4 million, and resulted in a 183-sector state model and 9 regional models. The regional models and the state model were developed using the same data. (Grubb, et al., 1973). Since the initial model became operational, continual maintainence and improvement have been carried out. However, such "enhancements" have not interfered with the application of the Input-Output model to numerous real problems by various state agencies, both in long term research/planning efforts and in the rapid analysis of short term operational situations.

One recent application in the latter case has dealt with assessing the impact of a recent rail strike on Texas' economy in an attempt to quantify the necessity for a rapid settlement and to analyze the implications of the alternate settlements. Another crucial use has been in developing a position to use to get a special exemption from the proposed fuel oil allocation to enable the farmers of Texas to harvest their crops. The Input-Output model is presently being used to assess the implications of various energy allocation strategies on the state in an attempt to influence the federal decisions concerning such allocations.

The expected costs of satisfying the stipulated cooling policies for each of the growth policies were developed in Section V.2. These cost changes are used to "trigger" an increase in the price of electricity in the utilities sales in Region 7 Input-Output model which corresponds to the South Texas Coastal Bend study area (Murrell, Grubb, et al. 1972). Since the regional economy is somewhat simpler than the overall economy of the state, the regional model has only 78 sectors rather than 183 sectors.

The transactions matrix is used for the calculations. A typical transactions matrix is shown in Figure V.4A. Sectors 1-71 are the processing sectors; rows 72-78 are the final payments sectors, and columns 72-78 are the final demand sectors. Sector 41 represents electric utilities, with row 41 showing the utility sales and column 41 showing the utility purchases.

The cost increase, "X", attributable to cooling processes is added to the total electrical sales and distributed proportionally across row 41 to all those sectors purchasing electricity. This procedure results in providing



SECTOR KEY

41 ELECTRIC UTILITY
70 EDUCATION
73 GOVT. FEDERAL
74 GOVT. STATE
75 GOVT. LOCAL
78 RESIDUALS (SAVINGS)
△ = INCREASE
O = DECREASE

TYPICAL TRANSACTION TABLE SHOWING PROCEDURE FOR TRACING RATE INCREASES
(AFTER LESSO, 1972)

FIGURE V. 4A

an "X" percent rate increase to the utility. This increase represents only an increase in price and does not represent a change in sales volume at any given point in time.

By increasing the total value of sales the revenue to the utility sector also is increased. For the case under consideration, this revenue increase is assumed to be going to pay for additional cooling equipment and operation of the equipment. However, some of this revenue also will go elsewhere. Since this type of cooling equipment is not tax exempt but is treated, for tax purposes, like any other capital improvement, the utility must pay taxes on all the revenue gained. Thus, the revenue to education and government will increase, since industry pays taxes to education and all levels of government. These increases are shown by "Δ's" in Figure V.4A.

This increase in revenue by the utilities obviously means that the sectors purchasing electricity must pay out more to the utilities sector. While these sectors will ultimately pass these increased costs of products and/or services on to the consumers, it can be reasonably assumed (Lesso, 1971) that the initial consumer reaction will be to pay these increased costs from residual income, also often called "residuals," "savings" or "discretionary income." For industries these funds are used for contributions for profits, retained earnings, funds available for dividends, etc. or just simply "cash in the bank." For households this residual income represents simple savings, i.e. cash put away, and not savings invested in bonds, stocks, etc. This extra expense will cause a decrease in the discretionary income for all sectors except utilities, education, and government as shown in Figure V.4A.

Application of Input-Output analysis procedure to the problem under investigation in this project requires several basic assumptions:

(1) The demand for electricity can be considered inelastic over the range of price changes being investigated.

(2) The assumptions of linearity inherent in the Input-Output model are valid over the ranges of price changes being considered.

(3) The general relationships between sectors of the economy can be considered valid over the time period being studied; however the absolute numbers in these relationships must be carefully scrutinized (i.e., ratios are more valid, than actual values).

(4) Processing sectors can generally be expected to pass any increased electrical costs along to the customers in the form of increases in the prices of goods and services. However, the initial burden of such increases will be met by funds from discretionary income.

(5) Households will initially meet the increased costs from their discretionary income. In the long run three courses of action are possible: decreased use of electricity, continuation of paying for increased rates from discretionary funds, or alteration of consumption patterns (i.e., buy less of something else). Overall response will be a mixture of the three preceding strategies.

Once the above assumptions are accepted, it is possible to apply the matrix adjustment procedure to the appropriate transaction tables and proceed with the analysis. However, before doing so, it will be valuable to develop some general understanding of the regional economy.

Regional Economic Structure

The study region is one of the more economically depressed areas in the state. Some revealing demographic data for the region are presented in Table V.4A and these data, especially the education, income, housing and occupational information are indicative of current conditions.

Since this study is about electrical energy, the sales of the utility industry (output, row 41) and purchases (input, column 41) are of principal concern.

Table V.4B shows the principal utility sales, both for the initial transactions table and a second case where a 10 percent price increase is assumed. Households (72) are by far the largest purchaser, accounting for direct sales of over $23 million, which is 37.4 percent of total electrical sales. Chemicals, drugs, and related (25) are second with $8.5 million, or 13.5 percent, and no other single sector accounts for more than 3.5 percent of sales. The ten sectors listed buy 72.7 percent of the total electricity sold in the region.

The purchases made by the utility from the top ten buyers of electricity also are listed in Table V.4B. It is worth noting that only households provide any significant goods/services to the utility.

The data presented in Table V.4B indicate that after the 10 percent rate increase, the utility sales to each sector are each up 10 percent in value. This increase simply shows the proportional distribution of extra utility revenue across those sectors purchasing electricity.

CHARACTERISTIC		PERCENT	
EDUCATION			
< 9 YEARS		38.0	
9-11 YEARS		18.5	
HIGH SCHOOL		23.9	
1-3 YRS. COLLEGE		10.6	
4 OR MORE YRS. COLLEGE		9.0	
FAMILY INCOME			
0-2000		19.4	
2000-6000		29.6	≤6000 : 49.0
6000-10,000		24.0	≤10,000 : 73.0
10,000-15,000		16.8	≥10,000 : 27.0
>15,000		10.2	
MEDIAN FAMILY	$ 7,429		
MEDIAN PER CAPITA (5.2 CAPITA/FAMILY)	1,444		
HOUSING			
MEDIAN RENT	$ 74 / MO.		
MEDIAN OWNER VALUE	10,212		
OCCUPATIONS			
PROF. ADMIN., TECH		21.8	
CLERICAL & SALES		21.4	
SKILLED & SUPERVISORY		15.0	
UNSKILLED & SEMI-SKILLED		41.8	

SELECT 1970 DEMOGRAPHIC DATA FOR STUDY AREA (U.S. CENSUS, 1970)
TABLE V.4A

SECTORS	BEFORE		AFTER	
	SALES	PURCHASE FROM SAME	SALES	PURCHASE FROM SAME
(1.) 72, HOUSEHOLDS	23,670.0	9,670.1	25,972.0	9,670.2
(2.) 25, CHEMS, DRUGS, ETC.	8,545.0	0.4	9,399.5	0.4
(3.) 70, EDUCATION	2,182.1	0	2,400.3	1,743.1
(4.) 13, CRUDE PET., GAS	2,071.3	0	2,278.4	0
(5.) 54, FOOD STORES	2,019.2	0	2,221.1	0
(6.) 29, PRIM METALS, FNDRYS.	1,973.1	0.6	1,972.5	0.6
(7.) 26, PET. REFIN. & RELATED	1,758.6	97.4	1,934.5	97.4
(8.) 49, GENERAL WHOLESALE	1,334.4	24.7	1,467.9	24.7
(9.) 63, LODGING SERVICES	1,246.0	0	1,370.5	0
(10.) 20, OTHER FOODS	1,218.1	0	1,340.0	0
TOTAL, ABOVE OUTPUTS	46,017.8	9,793.2	50,356.7	11,536.4
GRAND TOTAL, ALL OUTPUTS	63,256.4	63,256.4	69,582.1	69,582.1
% GRAND TOTAL IN ABOVE OUTPUTS	72.7%	15.5%	72.4%	16.6%

TOP TEN UTILITY SALES (OUTPUTS), BEFORE AND AFTER 10 PERCENT PRICE INCREASE (x10^3$)

TABLE V. 4B

Table V.4C is similar to Table V.4B except that the top ten purchases by the utility (i.e., where the industry's money goes). are shown. There is less distinction among the leading sectors in this case since the top five are residuals (78), \$18.7 million or 29.6 percent; households (72), \$9.7 million or 15.3 percent; federal taxes (73) \$9.6 million or 15.2 percent; gas (40) \$8.3 million or 13.1 percent; and depreciation (76) \$8.0 million or 12.6 percent. These top five sectors account for 85.8 percent of the total purchases by the utility; while the top ten sectors account for 96.4 percent. Of these 10 sectors, only households and education also are major buyers of electricity. It is interesting to note that combined payments to federal, state, and local governments account for \$11.9 million or almost 20 percent of the utilities income, whereas total fuel purchases (gas services plus imports) account for \$10.7 million or 17 percent. This situation of course is changing rapidly and by the end of 1973 fuel is the larger expense (Personal Communication).

While the dollar value of an electrical purchase by a processing sector is significant the overall importance of electrical energy to that processing sector is also very important. If two industries consumed the same amount of electrical energy, a person would normally assume that electricity was equally important to each. However this assumption could be very misleading if one facility happened to be a large, low-energy using concern whereas the other was a small energy-intensive operation. In the first case the electrical purchases might account for 0.25 - 0.50 percent of the sectors expenses whereas in the latter case it might be 5-10 percent. Obviously, the smaller, energy-intensive plant would be much harder hit by a significant increase in the price of electricity.

The direct requirements table of the Input-Output model is used to determine the importance to any sector relative to another. This table is simply a transactions table with each row scaled to one by dividing each

SECTORS	BEFORE		AFTER	
	PURCHASES	SALES TO SAME	PURCHASES	SALES TO SAME
(1.) 78, RESIDUALS	18,730.2	0	23,709.9	0
(2.) 72, HOUSEHOLDS	9,670.1	23,670.0	9,670.0	25,927.0
(3.) 73, GOVT.-FEDERAL	9,643.2	875.2	10,607.5	963.2
(4.) 40, GAS SERVICES	8,343.9	237.4	8,343.9	261.1
(5.) 76, DEPRECIATION	7,972.4	0	7,972.4	0
(6.) 77, IMPORTS	2,349.6	0	2,349.2	0
(7.) 70, EDUCATION	1,584.6	2,182.1	1,743.1	2,400.3
(8.) 75, GOVT.-LOCAL	1,245.1	29.4	1,369.6	32.4
(9.) 74, GOVT.-STATE	985.7	282.2	1,084.3	310.4
(10.) 38, OTHER TRANSP.(PL,RR)	440.0	369.3	440.0	406.2
TOTAL, ABOVE INPUTS	60,964.8	27,645.6	67,290.5	30,300.6
GRAND TOTAL, ALL INPUTS	63,256.4	63,256.4	69,582.1	69,582.1
% GRAND TOTAL IN ABOVE INPUTS	96.4%	43.7%	96.7%	43.5%

TOP TEN UTILITY PURCHASES (INPUTS) BEFORE AND AFTER 10 PERCENT PRICE INCREASE ($ x 10^3)
TABLE V.4C

transaction entry by the column total. Table V.4D shows those industries which spend one percent or more of their total budget on electrical energy.

Most of those industries spending more than one percent of their budget are relatively small consumers of electricity utilizing energy-intensive processes. It is interesting to note that wholesale farm products (45) is the most electrical energy-intensive industry with 6.67 percent of its budget being spent on electricity. This observation is true only for this region, and probably not for any other region and definitely not for the state as a whole. Water and sanitary services (42) also spends over six percent (6.34) of its budget on electrical energy This expenditure is the result of the widespread use of electrical pumps to produce ground water and to move surface water and wastewater.

Of the industries spending more than two percent of their budget of electricity, only two, lodging services (63) and chemicals, drugs, and related (25), appear in the top ten energy purchasers. The largest purchaser, households (72) which buys 37.9 percent of all electricity produced, ranks 27th in terms of the importance of its electrical purchases as compared to other purchases. These data simply show that while a given sector may account for a large percentage of total electrical sales (and demand), and thus be very important to the utility industry, each individual unit (i.e., firm) may spend only a small fraction of its budget on electricity. Careful scrutiny of Tables V.4A - V.4D will provide additional information about the structure of the regional economy which may be helpful in following the assessment of the economic impact caused by price increases resulting from cooling-related expenditures needed to meet the cooling policy constraints.

DIRECT REQUIREMENT (AS % TOTAL EXPENDITURE)	SECTOR	
≥6 %		
6.34	42	WATER AND SANITARY SERVICES
6.67	45	WHOLESALE FARM PRODUCTS
5-6%		
5.65	10	COTTON GINNING
5.02	*63	LODGING SERVICES
5.31	66	MOVIES AND AMUSEMENTS
4-5 %		
4.87	*25	CHEMICALS,DRUGS AND RELATED
4.61	27	CLAY, STONE AND SHELL
3-4 %		
NONE	NONE	
2-3 %		
2.03	35	MOTOR FREIGHT AND WAREHOUSING
2.67	57	APPAREL AND ASSESSORIES
2.67	58	HOME FURNISHINGS
2.75	64	PERSONAL SERVICES
1-2 %		
1.42	9	AGRICULTURAL SUPPLIES
1.44	*20	OTHER FOODS
1.78	*29	PRIMARY METALS & FOUNDRIES
1.70	34	OTHER MANUFACTURING
1.35	44	WHOLESALE - GROCERIES
1.36	*49	WHOLESALE -GENERAL
1.76	52	HARDWARE, HEATING & ELECTRICAL
1.30	*53	DEPARTMENT STORES
1.51	*54	FOOD STORES
1.38	59	EATING & DRINKING ESTABS.
1.48	60	OTHER RETAIL
1.23	62	INSURANCE, REAL ESTATE, FINANCE
1.14	68	OTHER MISC. SERVICES
1.42	*69	MEDICAL & DENTAL
1.37	*70	EDUCATION
1.34	*72	HOUSEHOLDS

*DENOTES AN INDUSTRY IN "TOP TEN" PURCHASES OF ELEC.

INDUSTRIES SPENDING MORE THAN ONE PERCENT OF BUDGET ON ELECTRICAL ENERGY

TABLE V. 4D

Computing the Impact of Cooling Costs

At the 1970 initial conditions, cooling related costs accounted for approximately 4.6 percent of the cost of delivered electricity - i.e., out of every $1.00 spent by the utility, 4.6¢ could be directly attributed to cooling (Figure V.4.1). Note that this cost is for delivered electricity, and not just for the generation process. Such delivered costs include transmission, distribution, and the whole complex of related services routinely provided by an electric utility. While the cost varies substantially, generation cost normally is only about 40 percent of the total cost, therefore if C_1 cooling accounts for 4.6 percent of the total cost, it would account for 11.5 percent of generation costs.

This 4.6 percent is based on the C_1 policy. It is necessary to determine how this value would increase under the C_2 and C_3 policies through time. Table V.4E shows the C_1, C_2, and C_3 expenditures, plus the ratio of C_2/C_1 and C_3/C_1 for each growth policy in 1970, 1980, 1990, and 2000. These ratios may be multiplied by the base 4.6 percent to obtain the estimated percent expenditures for C_2 and C_3 which are shown in Table V.4F, for 1970, 1980, 1990, and 2000.

This base 4.6 percent is derived from the fact that the estimated C_1 policy cost for 1970 is $1.58 million. One-half the population in the area covered by the Region 7 Model is in the Coastal Bend area; therefore, the total Region 7 cooling expenditures would be $3.16 million (double $1.58 million). Total sales were $69.58 million, or 3.16/69.58 = 4.6 percent. In order to assess economic meaning from these data, as well as other data previously presented, several individual sectors will be examined.

YEAR	GROWTH POLICY	COOLING POLICY C1 M$(c1/c1)	C2 M$(c2/c1)	C3 M$(c3/c1)
1970	ZPG	1.58(1.00)	1.87(1.18)	1.89(1.20)
	INT	" "	" "	" "
	COC	" "	" "	" "
			(1.18)*	(1.20)*
1980	ZPG	2.40(1.00)	2.97(1.23)	4.52(1.88)
	INT	2.47(1.00)	3.05(1.23)	4.65(1.88)
	COC	2.56(1.00)	3.18(1.24)	4.87(1.90)
			(1.23)*	(1.89)*
1990	ZPG	3.09(1.00)	3.89(1.26)	6.52(2.11)
	INT	3.39(1.00)	4.28(1.26)	7.68(2.27)
	COC	3.67(1.00)	4.59(1.25)	8.53(2.32)
			(1.26)*	(2.23)*
2000	ZPG	3.09(1.00)	3.89(1.26)	6.52(2.11)
	INT	3.59(1.00)	4.59(1.27)	8.25(2.30)
	COC	4.14(1.00)	5.26(1.21)	9.66(2.33)
			(1.27)*	(2.25)*

* AVERAGE

RATIO OF THE COST OF C_2 AND C_3 POLICIES TO C_1 POLICY FOR VARIOUS GROWTH PROJECTIONS

TABLE V. 4E

TIME	PERCENT TOTAL COST			DIFFERENCE	
	C_1	C_2	C_3	C_2-C_1	C_3-C_1
1970	4.6%	5.4%	5.5%	0.8	0.9
1980	4.6%	5.7%	8.7%	1.1	4.1
1990	4.6%	5.8%	10.3% (9.7, 10.4, 10.7)*	1.2	5.7
2000	4.6%	5.8%	10.4% (9.7, 10.6, 10.7)*	1.2	5.8
AVERAGE	4.6%	5.7%	8.7%		

* INDIVIDUAL VALUES SHOWN FOR ZPG, INT, AND COC POLICIES

PERCENT OF TOTAL ELECTRICAL COST ATTRIBUTABLE TO COOLING UNDER DIFFERENT POLICIES

TABLE V.4F

Households

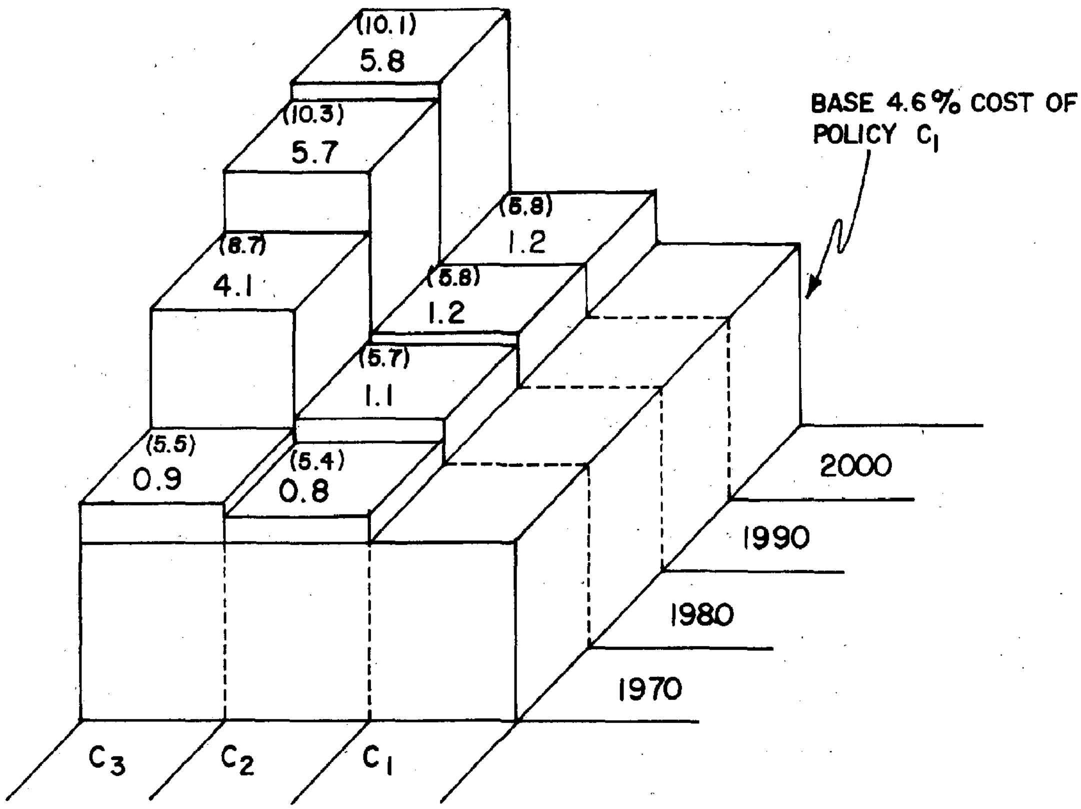
The initial question that most will ask is "How will this rate increase effect the man-on-the-street, i.e., the consumer?" The answer must be presented in two parts:

(1) Direct Effects - How will the electric bill change? and

(2) Indirect plus Induced Effects - How will the consumer ultimately "feel" the increased energy costs in the many goods and services he purchases?

Determining the direct costs is rather straightforward; the percentage increase in electrical costs appears as the same percentage increase in the monthly electrical bill. The percent increases in monthly (or annual) electric bills that a household (or any other sector) could expect for the C_2 and C_3 policies are shown in Figure V.4B. These increases are in addition to the base 4.6 percent cooling cost that is implicit in the C_1, or "present practice" cooling policy. It is obvious that the direct impact of the C_2 policy is never very great. Even the C_3, or "zero-discharge" policy does not appear to have a greatly significant direct impact, since it would only increase the electric bill by approximately 5.8 percent.

The next logical question is "How will the households react to this price increase?" The answer is not so straightforward. In fact, this question could keep an army of economists and sociologists arguing from now until the year 2000. One previous effort (Lesso, 1972) explored several possible reactions; based upon those efforts, this study will analyze the effect of the "most likely" reaction strategy. This approach simply assumes that the households will, in the short run, pay this increased cost out of their discretionary or "residual" income. Thus, the impact of this direct cost increase on the discretionary household income must be examined. The decrease in household discretionary income resulting from direct increases

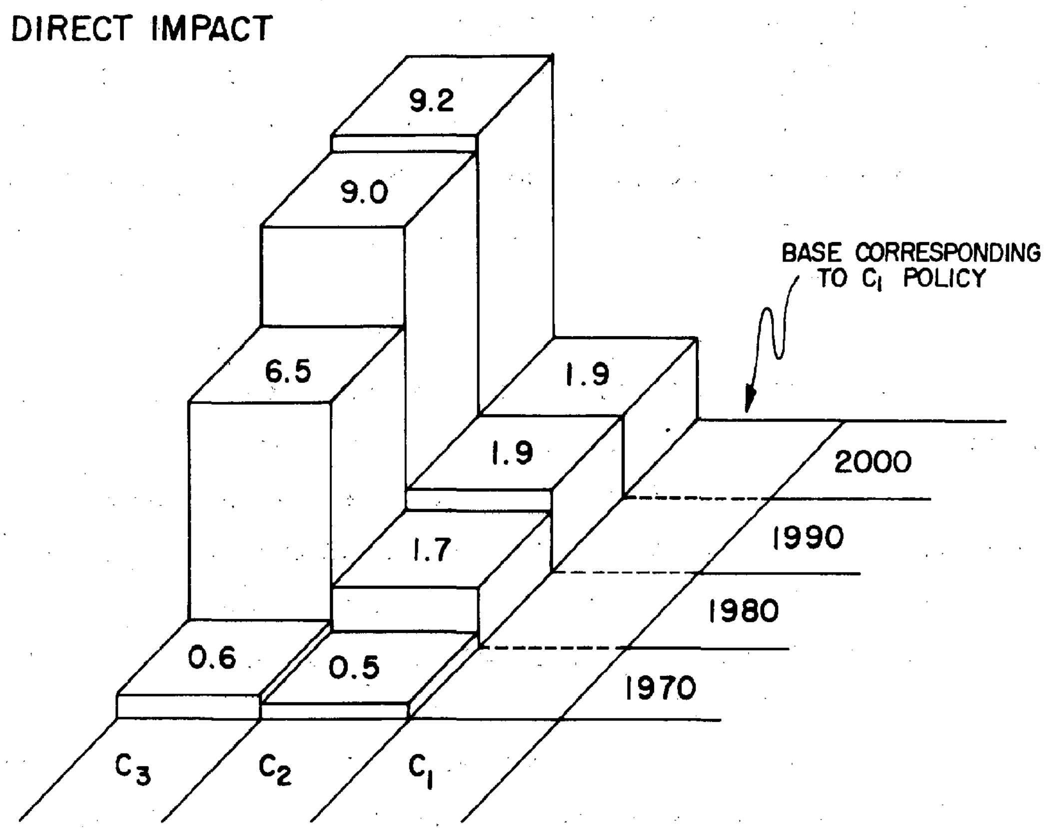


INCREMENTAL DIRECT INCREASE OF "ELECTRIC BILL" RESULTING FROM DIFFERENT COOLING POLICIES (PERCENTS)

FIGURE V. 4B

in electric rates as required to satisfy the C_2 and C_3 cooling policies is shown in Figure V.4C. The effect of C_2 is relatively insignificant; however, in the future, meeting the direct costs of C_3 could require almost 10 percent of the total household discretionary income. For some higher income families, with significant discretionary funds, this outlay probably would not be felt; however such an increase could cause a hardship on certain lower income families. Recalling that the average rent payment in the region is only \$74.00 per month, and that the income of half the families is less than \$6,000 per year helps provide some perspective.

Table V.4G shows the total annual per capita and per family costs related to cooling. These costs include not only direct costs presented previously but all the cost increases hidden in the goods and services purchased by the household. The annual total per family costs attributable to cooling are shown in Figure V.4D. This figure indicates the additional costs required for C_2 and C_3 in addition to the minimum base cost for C_1. The data in Figure V.4D indicate that for the 1990-2000 cases the estimated annual cooling cost to meet C_3 will be \$74.43 per family as compared with a C_1 cost of \$33.24 per family or \$41.93 per family for the C_2 case. These data indicate an average difference of about \$40.00 per family per year between the present practice policy and the zero-discharge policy. While this may not sound like much money, one must remember that the average rent payment if only \$74.00. However, for the Mexican Americans, which constitute 46 percent of the regional population, average rent drops to only \$55.00, and the average annual per capita income is only \$749.00. Nothing definitive to a quantitative scientist can be extracted from these numbers; however, these data cannot help but provide a meaningful and valuable insight into the socio-economic character of the study area. Hopefully, such numbers indicate that while such cost increases may seem almost trivial to many, such costs can be very significant to a substantial portion of the residents in the service area.



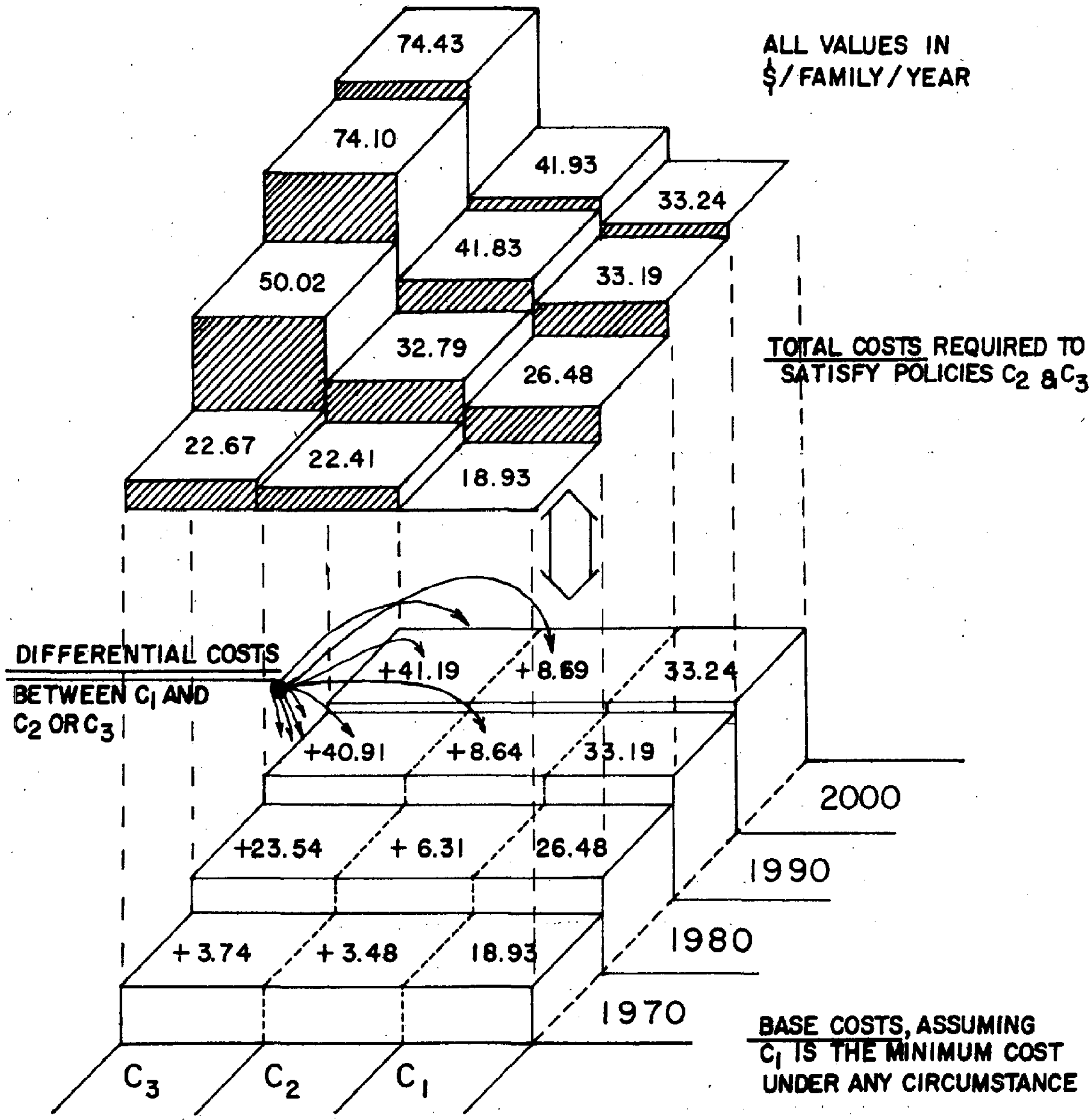
DECREASE IN HOUSEHOLD RESIDUAL INCOME DUE TO DIRECT INCREASE IN "ELECTRIC BILL" RESULTING FROM DIFFERENT COOLING POLICIES (PERCENT)

FIGURE V.4C

YEAR	GROWTH POLICY	POP ($\times 10^3$)	#/FAMILIES ($\times 10^3$)	TOTAL ANNUAL COOLING COST* \$/CAPITA/YEAR			TOTAL ANNUAL COOLING COST* \$/CAPITA/YEAR		
				C_1	C_2	C_3	C_1	C_2	C_3
1970	SAME	433.7	83.40	3.64	4.31	4.36	18.93	22.41	22.67
1980	ZPG	470.0	90.30	5.11	6.32	9.62	26.57	32.86	50.02
	INT	483.3	93.13	5.10	6.30	9.60	26.52	32.76	49.92
	COC	505.0	72.12	5.07	6.30	9.64	26.36	32.76	50.13
1990	ZPG	475.0	91.35	6.51	8.19	13.73	33.85	42.43	71.40
	INT	540.0	103.85	6.27	7.93	14.22	32.60	41.24	73.94
	COC	576.0	110.77	6.37	7.96	14.80	33.12	41.39	79.96
							(33.19)	(44.83)	(74.10)
2000	ZPG	475.0	91.35	6.51	8.19	13.73	33.85	42.43	71.40
	INT	570.0	109.62	6.30	8.02	14.47	32.76	41.70	75.24
	COC	655.0	125.96	6.37	8.01	14.80	33.12	41.65	76.65

* THE TOTAL ANNUAL COST PER CAPITA AND PER FAMILY COSTS ARE COMPUTED BY DIVIDING THE ESTIMATED COOLING COSTS (FIGURE V.2D) BY POPULATION OR NUMBER OF FAMILIES AS APPROPRIATE. THIS ASSUMES THAT ALL THE COOLING COSTS, BOTH DIRECT & INDIRECT ARE BORNE BY THE REGION. EVEN THOUGH SOME COSTS WILL BE EXPORTED WITHIN PRODUCTS EXPORTS, IT IS REASONABLE TO ASSUME THAT AN EQUAL AMOUNT OF SUCH HIDDEN COOLING COST IS IMPORTED WITH IMPORT PRODUCTS.

TOTAL ANNUAL PER CAPITA AND PER FAMILY COOLING-RELATED COSTS
TABLE V. 4G



TOTAL PER FAMILY COSTS ATTRIBUTABLE TO COOLING FOR SATISFYING VARIOUS COOLING POLICIES
($/FAMILY/YEAR)

FIGURE V.4D

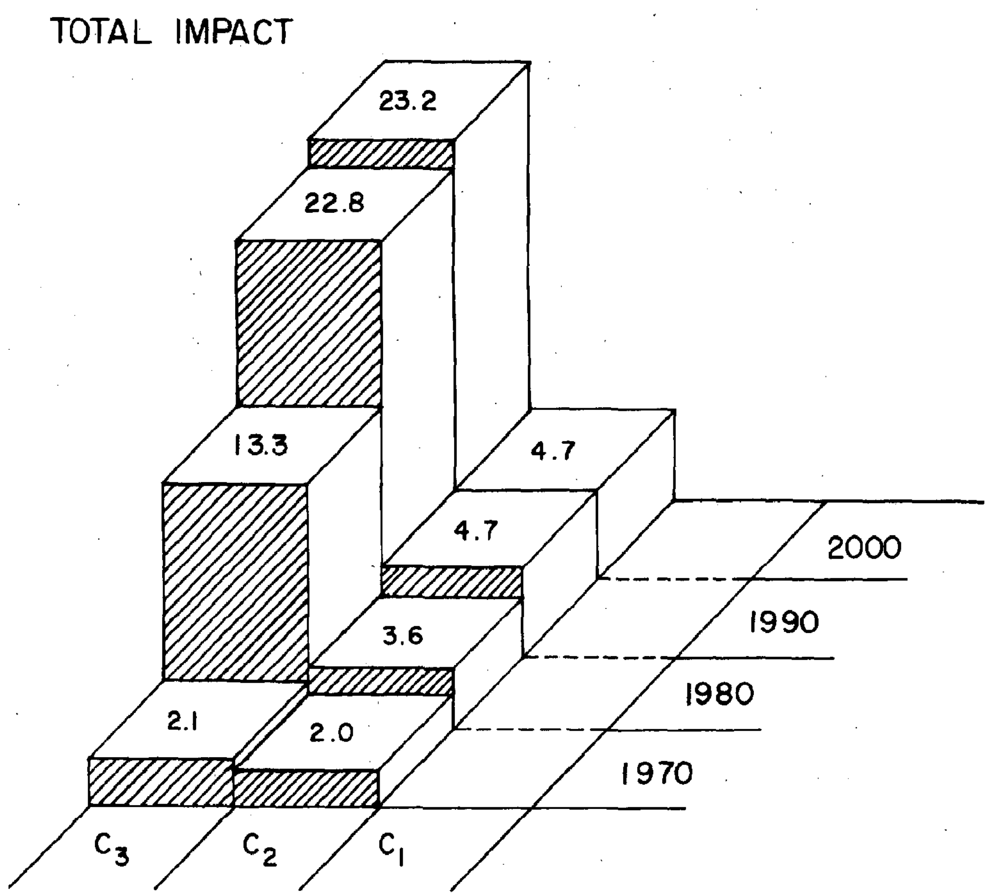
Next, the effect of the total cost increase on discretionary household funds will be examined. For this case it is assumed that the increased costs of all goods and services affected by the rate increase, as well as the direct increase in the electric bill to the household, will be borne by discretionary funds.

All three growth policies are aggregated and the average value is used. This aggregation makes the graphics easier to follow, and the unit values are close enough that no significant analytical resolution is lost.

In order to ascertain the effect of such costs on future discretionary funds, two key assumptions are requisite, namely (a) the fraction (percent) of total household outlays going as residuals will remain constant over time as the economy grows, and (b) although dollar values will change, the relative interdependence among sectors will remain constant over the study period.

The decrease in household residual income caused by the total (direct and indirect and induced) increase in electric rates is shown in Figure V.4E which indicates that the total costs can require 22-23 percent of the total household discretionary income to meet the C_3 policy, but only 4-5 percent to satisfy the C_2 conditions. These increases compare with 9-10 percent and about 2 percent, respectively to meet only the direct cost. (Compare Figures V.4C and V.4E to get a good perspective of the difference.) Thus the total economic impact on household residual income of meeting the C_2 and C_3 requirements is approximately 2 1/2 times the direct impact of satisfying the same environmental cooling criteria.

Assessing the impact of widespread price increases on personal and family income is always somewhat speculative. This previous discussion has attempted to illustrate some of the ways to try and obtain a perspective of



DECREASE IN HOUSEHOLD RESIDUAL INCOME DUE TO OVERALL ECONOMIC IMPACT RESULTING FROM DIFFERENT COOLING POLICIES

FIGURE V. 4E

what such numbers may mean from a social or socio-economic viewpoint. Such numbers don't provide "answers" in the conventional sense sought by engineers; however, they do provide some information which is certainly better than nothing except verbal rhetoric.

Processing Sector Impact

The initial industrial reaction to increased electric rates will be to cover this added cost out of residual income; in the long run such costs will be passed on to purchasers of the various goods and services produced by the affected industries. For households, residuals are often referred to as "savings", but the meaning for industry is different; here retained earnings, contributions to profit, funds available for dividends, etc. are all included.

To obtain a concept of the impact of cooling cost increases on the processing sectors, the most expensive cooling condition, C_3, was assumed to occur. Each industry was expected to meet the resulting electrical increase of 5.8 percent from its available residual income. (Sixteen sectors, mostly agricultural, showed either a negative or zero residual income in the model and will be discussed separately.)

A list of the 71 processing sectors ranked according to the percent decrease in residual income is given in Table V.4H and a plot of these same data is presented in Figure V.4F. One thing becomes evident: the 5.8 percent cost increase required to meet the C_3 cooling policy does not have a significant, widespread impact on the residual incomes of the regional processing sectors.

One industry, wholesale farm products (45) appears to be the hardest hit, with a 37.8 percent decrease in residual income. However, a couple of associated facts must be brought out. First, during the year on which the

PERCENT REDUCTION	SECTOR NUMBER AND NAME	
37.82	45	WHOLESALE FARM PRODUCTS
6.50	42	WATER AND SANITARY SERVICES
5.07	70	*EDUCATION
4.18	49	GENERAL WHOLESALE
1.80	25	CHEMICALS, DRUGS AND RELATED
1.71	58	FURNITURE AND HOME FURNISHINGS
1.57	63	LODGING SERVICES
1.36	29	PRIMARY METALS, FOUNDRIES
1.19	56	GASOLINE SERVICE STATIONS
1.07	66	MOTION PICTURE AND AMUSEMENTS
1.00	9	AGRICULTURAL SUPPLY
.84	64	PERSONAL SERVICES
.77	47	WHOLESALE MACHINERY AND EQUIPMENT
.71	30	FABRICATED STEEL AND OTHER PRODUCTS
.50	11	AGRICULTURAL
.45	57	APPAREL AND ACCESSORIES
.43	24	NEWSPAPERS, PUBLISHING AND PRINTING
.42	68	MISC. REPAIRS SERVICES
.40	20	OTHER FOOD AND KINDRED PRODUCTS
.31	62	FINANCE, INSURANCE AND REAL ESTATE
.29	23	WOOD FURNITURE, PAPER AND RELATED
.28	53	DEPARTMENT AND VARIETY STORES
.26	65	ADVERTISING, DUPLICATING, PHOTO SERVICES
.26	39	COMMUNICATIONS
.24	19	FROZEN, CANNED, DRIED AND PRESERVED FOODS
.23	44	WHOLESALE GROCERIES
.23	21	BEVERAGES
.22	69	MEDICAL AND DENTAL SERVICES
.22	60	OTHER RETAIL
.19	55	AUTO DEALERS AND REPAIR SHOPS
.18	59	EATING AND DRINKING PLACES
.14	54	FOOD STORES
.14	26	PETROLEUM REFINING AND PRODUCTS
.14	35	HIWAY MOTOR FREIGHT AND WAREHOUSING
.11	71	PROFESSIONAL SERVICES
.09	43	WHOLESALE AUTO PARTS

(TABLE CONTINUED ON NEXT PAGE)

TABLE V. 4H

(CONTINUATION OF TABLE V. 4H)

PERCENT REDUCTION	SECTOR NUMBER AND NAME	
.08	13	MINING-PETROLEUM AND GAS
.08	31	MACHINERY AND PROCESSING EQUIPMENT
.08	51	FARM EQUIPMENT DEALERS
.04	61	BANKING AND CREDIT AGENCIES
.04	38	OTHER TRANSPORTATION
.01	48	WHOLESALE PETROLEUM AND PRODUCTS

SECTORS EXPERIENCING LESS THAN 0.01 PERCENT REDUCTIONS

18	DAIRY MANUFACTURING
28	CEMENT AND CONCRETE PRODUCTS
32	ELECTRICAL AND ELECTRONIC EQUIPMENT
33	TRANSPORTATION EQUIPMENT
34	OTHER MANUFACTURING
36	WATER TRANSPORTATION
37	AIR TRANSPORTATION
40	GAS SERVICES
46	WHOLESALE LIVESTOCK
50	RETAIL LUMBERYARDS
52	HARDWARE, WALLPAPER, HEATING, ETC.
67	AUTO RENTALS AND PARKING SERVICES

SECTORS HAVING AN INITIAL RESIDUAL INCOME OF ZERO OR A NEGATIVE VALUE (SEE TEXT FOR EXPLANATION)

1	IRRIGATED COTTON
2	IRRIGATED GRAINS
3	IRRIGATED VEGETABLES & CITRUS
4	DRYLAND COTTON
5	DRYLAND FEED GRAINS
6	OTHER DRY LAND CROPS
7	LIVESTOCK RANGE AND FEEDLOT
8	DAIRY, POULTRY AND EGGS
10	COTTON GINNING
12	FISHERIES
14	RESIDENTIAL CONSTRUCTION
15	COMMERCIAL & INSTITUTIONAL CONSTRUCTION
16	FACILITY & OTHER CONSTRUCTION
17	MEAT PRODUCTS
22	TEXTILE MILL PRODUCTS
27	CLAY, SHELL AND CUT STONE

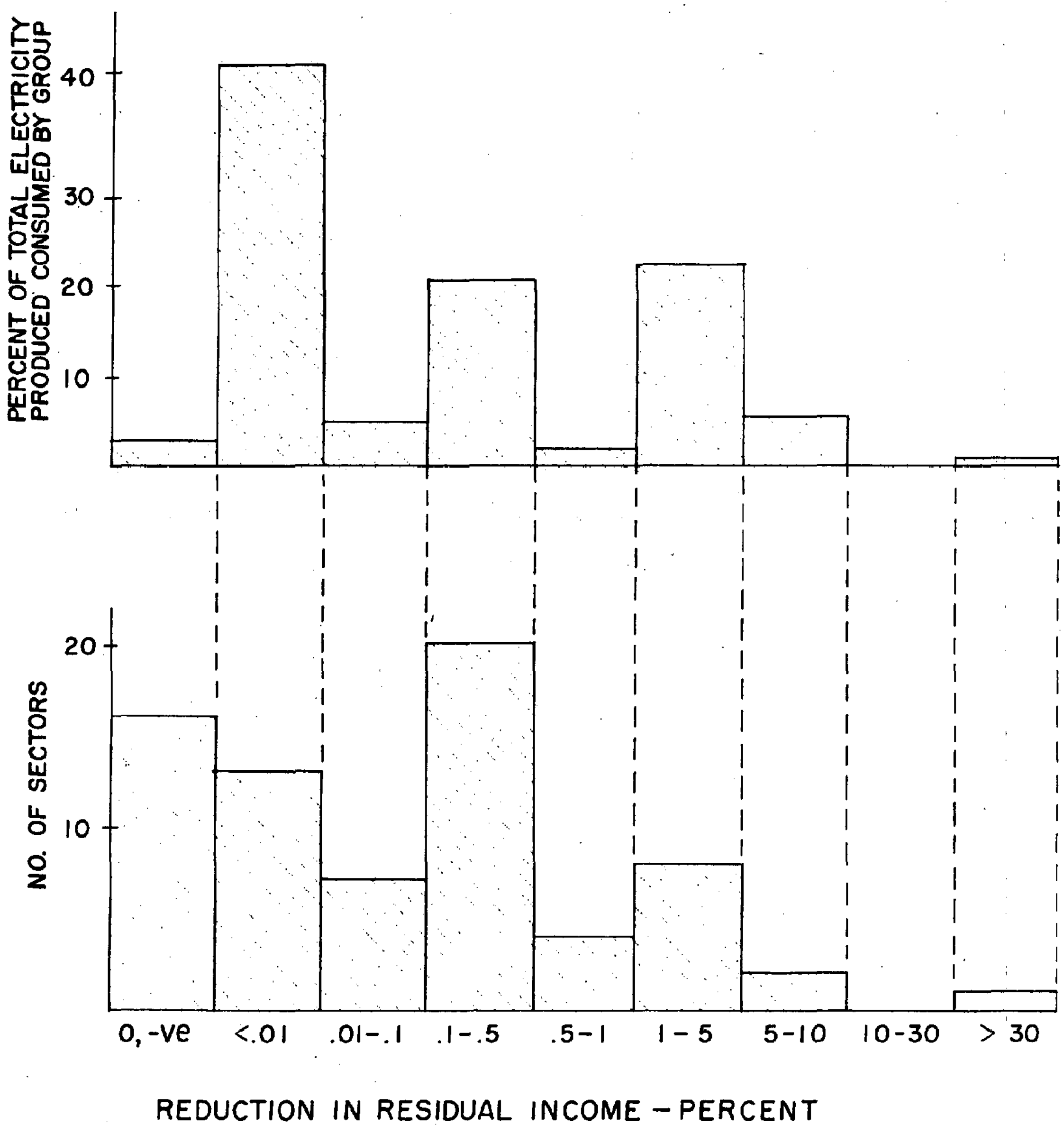
(TABLE CONTINUED ON NEXT PAGE.)

(CONTINUATION OF TABLE V. 4H)

FOOTNOTES

1. * EDUCATION SHOWS A DROP IN RESIDUAL INCOME $34,800, HOWEVER IT HAS AN INCREASE IN REVENUES OF 1,081,000 FROM UTILITY TAXES WHICH OFFSETS THE RESIDUAL LOSSES MANY TIMES OVER.
2. THE UTILITY SECTOR, #41, IS THE ONLY PROCESSING SECTOR NOT SHOWN IN THIS TABLE. ITS RESIDUAL WOULD APPEAR TO INCREASE BECAUSE OF INCREASED REVENUES; HOWEVER THIS INCREASED INCOME IS EARMARKED FOR COOLING-RELATED EXPENSES.

(END OF TABLE V. 4H)



EFFECT ON RESIDUAL PROCESSING SECTOR TO MEET STRICTEST COOLING POLICY

FIGURE V. 4F

Input-Output model is based, the region suffered a late season hurricane which brought very heavy rains to the region and devastated many of the area's crops in the fields. This phenomenon would tend to make it a tough year for the wholesale farm products industry. Compounding this apparently very large impact further is the fact that this industry is rather small, (accounting for only 0.4 of one percent of electrical purchases) and always operates on a narrow profit margin. However electricity is a major expense for this sector, with 6.7 percent of all revenue being spent on electrical energy. It is also a sector in which prices often change rapidly to reflect fluctuations in costs, supply, and demand. Thus, to infer that an increase in power cost would consume the residual income and wipe out the industry would be most improper. It would be possible to suggest that some of the marginal and/or smaller operators might be driven out of business.

On the basis of percent decrease in residual income, water and sanitary services (42), is the second most affected industry with 6.5 percent of its residual income being required to pay the cost of additional cooling. This sector is an intermediate consumer of electricity, ranking 13th and accounting for 1.6 percent of the total regional electrical demand. However electrical energy is one of this sector's major expenses, requiring 6.3 percent of total income. This sector includes both public and private water and wastewater facilities but the great majority are public, non-profit operations, and because of their public nature, very little residual income is generated, in fact only about 4.4 percent of revenue goes to residuals as compared to 10-30 percent in other sectors. Thus, a small electrical cost increase, if allocated to residuals, could appear to have a devastating effect on the water and wastewater utility service, but to predict doom for this industry would be ridiculous. When costs increase in this sector, they are apt to be quickly passed along as rate increases to water and sewer customers. Payments to water and sanitary services are generally a very insignificant portion of other sectors expenses. With the exception of lodging services (63), whose payments to this sector constitute 3.8 percent of its revenue, other sectors spend less than 0.1 - 0.2 percent for water and sanitary services. Thus, it is safe to say that increased electrical costs to the water and sanitary utility sector would not be significantly felt.

Education (70) shows up third in Table V.4H, but this is also very deceptive. The costs for the Education sector will go up substantially, and devour a good portion of what residual income this sector has. However, the education sector will experience a marked increase in revenue, resulting from increased electric utility taxes, which will compensate for increased power costs several times over.

The general wholesale sector (49) will use 4.18 percent of its revenue to meet the added cooling costs imposed by C_3. This sector has a substantial electrical demand totaling almost \$1.5 million per year; this makes it the 7th largest electrical customer. This sector generally does not constitute a major item in budgets of other sectors, usually running under 1.0 percent of expenses. There is one exception: agricultural supplies (9) which spends 16.7 percent of its outlay on general wholesale, and next to households, this cost is the most expensive category for the agricultural supplies sector. However, agricultural supply is such a small sector (only four sectors, 27, 32, 46, and 67 are smaller) that even if general wholesale price increases hit agricultural supply, the effects would not have a significant effect beyond that single sector. Thus, it is reasonable to conclude that power cost increases would neither greatly affect the general wholesale sector nor trigger any related secondary impacts.

The next ranking sector to be affected is chemicals, drugs, and related (25). The characteristics of this sector can be contrasted with the others previously mentioned. To begin with, these industries buy and use more electricity than any other processing sector, with annual purchases totaling \$8.5 million or 13.5 percent of all electrical sales. Electrical energy accounts for 4.9 percent of all expenses for this sector. Residual income is typically high for this industry, a fact that indicates the type of investors who back this industry. Such investors expect sizable dividends and rates of return on their investments and such payouts must come from the residual sector. This sector's sales to others often constitutes a sizable portion (often 8-10 percent with some in excess of 20 percent) of the purchasing sector's budget, thus making the operation of many other sectors sensitive to the price of chemicals, drugs, and related. Considering this fact, it is reasonable to conclude that even a fairly small increase in electrical costs could cause a "jolt" in this sector that very possibly might be transmitted to other sectors of the economy. It could be logically argued that of the processing sectors discussed thus far, this sector is the first one where even small increases in the cost of electricity might produce significant or even detectable repercussions on the regional economy.

Six other sectors, shown in Table V.4H, will have their residual income decreased by more than 1.0 percent to meet the cost of the C_3 cooling policy. However, by examining the sectors, it is reasonable to conclude that there will be no substantive regional economic impact. The same can be said for the remaining 43 sectors showing a reduction inresidual income of less than 1.0 percent.

Table V.4H also shows 16 other sectors which had a zero or negative residual income in the initial Input-Output tables. Obviously it is not possible to assess their sensitivity to electricity costs by the above method, thus they must be examined separately. All of this group, with exception of textiles (22) are either agriculture or construction. As mentioned earlier the region experienced a wet, early fall hurricane in the year on which the Input-

Output model is based. The hurricane dealt a devastating blow to the agricultural sectors that year by ruining most crops in the fields, and thus, agricultural profits never occurred. However, it is worth mentioning that agriculture quickly recovered, and the revised model currently being developed will reflect this healthy state. The same natural disaster also dealt the construction industry a severe blow, but it too has quickly recovered, and is now more healthy than ever. No such simple explanation can be given for textiles, but it is a minor activity whose fortunes tend to vary greatly.

Another approach can be used to get some idea of the impacts electrical cost increases will have on the sixteen sectors showing a zero or negative residual income. The data shown in Table V.4I indicate the importance of electrical energy to other sectors by showing what fraction of their budget is spent on electricity. Fourteen spend less than 0.5 percent on electricity. It is safe to conclude that they will be essentially unaffected by the 5.8 percent cost increase necessary to cover policy C_3 costs.

Cotton ginning (10) with 5.6 percent of its budget going to electricity will be affected by rate increases; however, the cost of ginning is a minor fraction of the cost in cotton production and processing, and any added costs can be passed along. Ginning is usually a low-profit venture at best, and such cost increases may drive a few marginal firms out of business; however, because of the ginning industry the effects of such closures would be localized.

Clay, shell and cut stone (27), spends 4.6 percent of its budget on electricity. Most of this goes for making brick from clay. However, it is the smallest of the 71 processing sectors, and uses only one-tenth of one percent of the region's electricity. While this sector does sell to many other sectors, the dollar values involved are very small, usually less than 1/1000 of one percent of the purchaser's budget and never more than one half of one

SECTOR NUMBER AND NAME		PERCENT BUDGET SPENT ON ELECTRICITY
1.	IRRIGATED COTTON	.24
2.	IRRIGATED GRAINS	.25
3.	IRRIGATED VEGTABLES & CITRUS	.27
4.	DRYLAND COTTON	.21
5.	DRYLAND GRAINS	.29
6.	OTHER DRYLAND CROPS	.24
7.	LIVESTOCK, RANGE & FEEDLOT	.15
8.	DAIRY, POULTRY & EGGS	.19
10.	COTTON GINNING	5.65
12.	FISHERIES	.34
14.	RESIDENTIAL CONSTRUCTION	.21
15.	COMMERCIAL & INSTITUTIONAL CONSTRUCTION	.19
16.	FACILITY & OTHER CONSTRUCTION	.19
17.	MEAT PRODUCTS	.49
22.	TEXTILE MILL PRODUCTS	.46
27.	CLAY, SHELL AND CUT STONE	4.60

ELECTRICAL ENERGY EXPENDITURES BY THOSE SECTORS SHOWING ZERO OR NEGATIVE RESIDUAL INCOMES

TABLE V. 41

percent. For these reasons it is safe to conclude that electricity cost increases would have no effect whatsoever on this sector or those to which it sells its products.

From the above, it is apparent that while no processing sector will completely escape being touched by cost increases in electricity, none should be devastated either. Several sectors initially appear to be very hard hit, but close scrutiny, thought, and independent inspection of the affected sector's general nature showed that initial fears were unwarranted. The one sector that might trigger secondary impacts was chemicals, drugs, and related (25). This situation was deduced from several facts: (a) it is the second largest purchaser of electricity, (b) electrical energy is a major item in its budget, (c) its residual income would be substantially affected; (d) investors backing this sector expect high returns, and possibly most importantly (e) this sector is a major supplier of other sectors. Thus, while it is not possible to predict just what might happen, it is possible to say that the chemical drugs, and related sector (25) deserves the most attention. While it is possible to say that no other sectors will be adversely affected as a whole, this is not true for certain firms within those sectors. It is only logical that if times get tight for any broad industrial category, the marginal firms will fold first and this is true here.

Summary of Regional Economic Impact

From the preceding analyses and discussions, several points can be concluded about the economic impacts of price increases on the regional economy:

(1) The Input-Output model, while it does have its limitations, can be manipulated so as to provide a general idea of what will occur and to identify which sectors will be the most affected. This enables one to concentrate on the significant

areas and avoid the unimportant. Also, if an Input-Output model is available, once the software to manipulate it is developed, it is very easy to examine a large number of possibilities.

(2) Households will not be particularly hard-hit by direct effects. However, the combined impact (direct plus indirect plus induced) could cost up to $72.00 per family per year for "zero discharge" cooling. This is equivalent to one month average rent and is approximately one-quarter of the average residual income.

(3) No processing sector should experience a major adverse impact, although limited tertiary effects may be felt through the chemicals, drugs and related sector (25). Some individual firms who are already marginal may be put out of operation.

(4) No "inflationary waves" will be triggered, although some localized effects are apt to be experienced.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

The principal objectives of this project are to develop a methodology for identifying and assessing the implications of alternative public policy decisions concerning the energy-environment dilemma, and to apply the methodology to a real-world situation in order to demonstrate its practicality. It is in the context of the above objectives that the following conclusions and recommendations will be presented. These findings are arranged into three sections: VI.1, Conclusions; VI.2, Recommendations for Action; and VI.3, Suggestions for Further Research.

VI.1 CONCLUSIONS

A. This project was successful in developing a realistic, feasible technique capable of evaluating certain implications, including trade-offs, of alternative public policy decisions dealing with the energy-environment dilemma.

1. The development and subsequent usage of such procedures for policy analysis depend upon the availability and reliability of proven analytical techniques and adequate information bases. This study could not have been done within the time and resources available if the Texas Input-Output Model had not been complete, and other data had not been previously compiled and analyzed on power plant sites and water resources.
2. Although the development of new, more sophisticated analytical techniques is desirable, meaningful policy analysis can be accomplished through the application of existing techniques and the thoughtful interpretation and use of available information.

3. Procedures for analyzing alternative public policies, such as the one developed and demonstrated herein, do not produce the single, hard, quantitative answer that most people continually seek. No such "single answer" exists to this sort of complex problem. Rather, a careful analysis will provide valuable improved insight into the interactions, critical elements, principal linkages, and predominant forces that govern complex real-world systems involving energy, environment, and economics. For this reason, those developing and using such techniques must possess a thorough understanding of the policy aspects involved and have a good understanding of the analytical techniques involved.

B. The application of this procedure to the Coastal Bend region in South Texas demonstrated that this approach can produce realistic meaningful results. Moreover, this application provided some most enlightening insights into the problems of power plant cooling and growth in the study area:

1. For the combinations of growth and cooling policies considered, natural resource availability will be a limiting factor in power plant siting and the selection of cooling systems. Cooling ponds are the most logical choice. Limited fresh water availability will constrain the use of evaporative towers; significant energy requirements will discourage dry towers; and the need to protect the bays from large additional heated discharges will eliminate once-through estuarine cooling. Another possibility, though remote at this time, is the use of offshore power plants.
2. The economic cost of meeting stringent heat discharge policies can be significant. Electric utilities are regulated monopolies, and it is customary to pass such increased costs along to the purchasers of electricity. The added cost of additional cooling will not cause any significant "inflationary waves" to be generated and permeated through the region's economy. However, certain individual

establishments, which are already marginal operators, are likely to be driven out of business, even though more healthy establishments in the same economic sectors will not be adversely affected.

3. The most pronounced socio-economic effect will be felt by certain households. Low income families are apt to be hit the hardest. The cost of implementing the "zero-heat-discharge" policy would cost the typical family one month's rent each year. The average per family total cost* of this policy would be $74 per year. While this may not sound like much money to many, according to the 1970 U.S. Census, this equals one month's average rent for this region.
4. Based on the preceding information it appears unwise to implement stringent environmental control policies without a careful evaluation of possible undesirable socio-economic implications. Extra caution should be exercised in severely economically depressed regions. The possibility of such socio-economic impacts cannot be disregarded by responsible public officials--regardless of how admirable their other objectives may be.
5. Occasions are apt to arise when the apparent solution to one environmental ill will create another problem that is worse than the original one. This would likely happen in the study area if evaporative towers were used for all cooling. These towers would require all available fresh water, and consequently eliminate fresh water inflows to the estuaries. Such an occurrence would almost certainly have a greater adverse ecological impact than the heated discharges.
6. From the experiences and results of this project, it can be concluded that there is a real need to utilize analytical techniques of the type presented here to assess the implications of alternative public policy decisions before any decision is implemented.

* This includes indirect and induced costs as well as the direct costs.

VI.2 RECOMMENDATIONS FOR ACTION

1. Expedite the implementation of the results of this effort by (a) keeping the presentation of results simple and utilizing graphical techniques whenever possible; (b) focusing on the application of such techniques to strategic-type policy decisions rather than to individual project decisions subject to established policies; (c) stressing the utility of the results and not the finer points of the analytical procedure; and (d) emphasizing the comparison of alternatives and not the absolute evaluation of each.

2. Instigate positive, aggressive measures to inform decision-makers that analytical procedures such as this do exist and that these procedures can be manipulated to provide insight into the implications of alternative public policies. Support the modification of institutional procedures that will bring about the application of this type of analytical technique to all proposed environmental management policies. Emphasize evaluation of the impacts of such policies on other natural resources and socio-economic goals and/or constraints.

3. Work through the appropriate state entities to encourage the application of this approach to assess the implications of the Clean Air Act and the Water Pollution Control Amendments on the State of Texas.

VI.3 SUGGESTIONS FOR FURTHER INVESTIGATIONS

1. An extension of this study should be undertaken in the Coastal Bend region to examine the effects of zero heat discharge applied to all industries. An expansion looking at the policy of zero-discharge for all wastes would be most valuable in order to examine the regional impact and to determine if such an expansion can be practically accomplished. Simultaneously, another investigation should be conducted for the purpose of identifying and quantifying the ecological benefits associated with such zero-discharge requirements.

2. This methodology should be applied state-wide for the utility industry to test the general applicability of the procedures, and to examine the effects over a larger and more complex economic system.

3. The Input-Output procedure should be modified to examine the effects of differing elasticity assumptions so that stratifications of different sized firms can be handled. The I-O model should be continually updated to insure that the best available data are utilized.

4. Studies should be initiated to evaluate the demand elasticity factors associated with electrical rates.

5. Basic research should be conducted to develop techniques for evaluating the social impact of policy decisions. Every possible effort should be made to enhance communications between the social and physical researchers with this goal in mind.

6. The methodology should be utilized to look at alternative land use allocation policies that are going to become a reality when the proposed National Land Use Policy Act becomes law and is implemented.

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